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Suppression of Pink Bollworm by Sterile Moth Releases

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ABSTRACT

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Pink bollworm, Pectinophora gossypiella (Saunders), moths, sterilized by irradiation (Co^{60}), were air-shipped from Phoenix, Ariz., to St. Croix, U.S. Virgin Islands, and released into cotton plots at various times from late 1980 through March 1982. This paper reports the results of the various aspects of the study, including how air-shipment affected moth survival, dispersal of released insects and abundance of St. Croix native male moths before and after sterile moth releases began and of released sterile males, mating status of native and released females, ratios of the four possible mating combinations, attractiveness and mating of mass-reared females (whether or not irradiated) to native and released males, and degree of infestation in cotton (in release plots and in control plots) before and after releases began. High numbers (about 100,000 per release day per 1.5 ha) of released sterile moths were needed to suppress high native larval infestation in bolls. The release system will be most effective when releases are started at the lowest population period after an overwintering host-free period or in combination with other suppression techniques to reduce populations before releases begin.

KEYWORDS: air-shipments; blacklight traps; chromosomal aberrations; cotton; gossyplure-baited traps; irradiation; mating tables; pink bollworm; Pectinophora gossypiella (Saunders); Phoenix, Arizona; released sterile moths; St. Croix, U.S. Virgin Islands; sterility

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SUPPRESSION OF PINK BOLLWORM BY STERILE MOTH RELEASES

By T. J. Henneberry and D. F. Keaveny III[1]

INTRODUCTION

The concept of sterile insect release was first suggested by Knipling (1959) in 1937 and successfully demonstrated as an effective technique for insect population suppression with the screwworm, Cochliomyia hominivorax (Coquerel), fly in 1955 (Baumhover et al. 1955). Later, the development of a pink bollworm, Pectinophora gossypiella (Saunders), artificial diet (Vanderzant and Reiser 1956) and mass-rearing technology (Richmond and Ignoffo 1964) stimulated research to determine the feasibility of using the method for pink bollworm control.

Graham et al. (1972) reported that newly emerged pink bollworm moths exposed to 25 krad of gamma radiation or more and crossed with untreated insects produced no fertile adult progeny. Sterile moth releases (15-40 krad) in field cages with untreated insects reduced developing pink bollworm populations 72 to 91 percent over two generations (Richmond and Graham 1970, 1971).

The results of these and other field-cage studies (Flint et al. 1974, Flint et al. 1975), recently reviewed by Bartlett (1978) and Henneberry (1980), indicated that the method showed promise as a control technology. However, several field studies with releases of sterile pink bollworm moths to evaluate the method for suppressing established populations of the insect were unsuccessful (Bariola et al. 1973, Graham 1978). This was attributed to lack of isolation from the influence of migrating native pink bollworm populations into the experimental areas and/or high native populations that made it difficult to obtain ratios of sterile-to-native insects sufficient to achieve population suppression.

Also, the impact of releases of sterile moths under field conditions may be influenced by possible adverse behavioral changes of the insects, as a result of selection in mass-rearing, that prevent mating interactions of released sterile insects with native insects (Boller 1972). Graham (1978) reported that, in the laboratory, mass-reared and irradiated pink bollworm males mated with native females produced as many spermatophores per female; and viability of eggs from mated

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females was not significantly different from similar data when native males were paired with mass-reared, irradiated females. These results indicated that mass-reared moths were compatible with their native counterparts. However, mass-reared males have been reported not to mate competitively with native females in field cages (Van Steenwyk et al. 1979) or as frequently with native females in laboratory studies (Henneberry and Clayton 1980, 1981; Henneberry et al. 1980).

The need to define the interaction of released sterile pink bollworm moths with native moths under field conditions and to evaluate the impact of releases of sterile moths on an established field infestation prompted us to begin studies on St. Croix, U.S. Virgin Islands, to provide this information. Also, since 1968, a cooperative U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS), California State Department of Food and Agriculture, and California cotton growers program has involved releasing sterile moths during each cotton growing season in the San Joaquin Valley of California (U.S. Department of Agriculture 1977). The purpose of this program is to prevent establishment of the insect in the area by migrating native moths from southern California and Arizona. In contrast, the studies conducted on St. Croix involved established native pink bollworm infestations. Populations were much higher than would be usual for the use of sterile moths in a population suppression program. Therefore, the results of the studies reported here are not necessarily indicative of the impact of releases of sterile moths when sterile to native moth ratios are many times higher than those obtained in the St. Croix experiments. However, the findings reported here should provide information useful in the conduct of current programs and should also serve as a guide to additional research.

HISTORY OF THE PINK BOLLWORM ON ST. CROIX

St. Croix is about 9.7 km wide and 37.0 km long, with an area of 21,862 ha. It was picked as an experimental site because it is relatively isolated (about 64 km south of St. Thomas and St. John and 97 km southeast of Puerto Rico) and has no commercial cotton production.

Sea Island cotton (*Gossypium barbardense* L.) seed was imported into the Virgin Islands about 1908 (Smith 1921). A cotton-breeding program was established in 1911, and, through selection and importation of additional Sea Island cottons, good progress was made in developing a satisfactory Sea Island cotton type suitable for commercial growing on the island. Pink bollworm infestations were found in St. Croix cotton in 1921, as well as in cotton growing on St. Kitts, Nevis, Montserrat, Antigua, and the British Virgin Islands (Smith 1922). Thereafter, cottons grown in 1921 and 1923 through 1930 were infested by the insect irrespective of attempted elimination of the pest by host-free periods in 1921 and 1922 and 1930 to 1932 (Ricks 1932). No commercial cotton has been grown on St. Croix since 1927. The pink bollworm has persisted in volunteer Sea Island cotton; wild cotton; and okra, *Hibiscus esculentus* L., as well as in other host plants such as *Thespesia populnea* (L.) and *Hibiscus vitifolius* L. (Loftin 1932). Surveys conducted from 1966 to 1968 of pink bollworm populations on St. Croix indicated that pink bollworm, as well as volunteer Sea Island cotton, were distributed over much of the island at elevations below 822 m (Graham and Cantelo 1973).

METHODS AND MATERIALS

Experimental Cotton Plots

Cultivated experimental cotton plots were maintained on the U.S. Department of Agriculture's Kingshill and nearby Virgin Islands Experiment Stations (figure 1) from June 1979 to July 1982 to provide continuous host material for St. Croix pink bollworm populations. Stalks of an existing experimental cultivated cotton plot on the Kingshill Experiment Station were cut back in June 1979. Cottonseed was planted in a 0.1-ha plot in July 1979 and in a 0.2-ha plot during October 1979. These plots were plowed down during May 1980 after plantings (next to existing plantings) of about 0.1 and 0.2 ha were started in January 1980; these were maintained through February 1981. Plots (four, about 0.1 ha each) were planted in the same area in June 1980 and maintained through October 1981, followed by plantings of four plots of about the same size planted in March 1981; these were maintained through May 1982. Cultivated cotton plots were also planted at five locations outside (about 1.6 to 18 km from plots on the Kingshill and Virgin Islands Experiment Stations) the sterile moth release area in August and September 1979. These plots were replanted in September to October 1980 and 1981 after the plants died due to lack of water during drought months of June through August of each year. Volunteer Sea Island cotton (fig. 1) was found at 22 sites over the island which were also used as experimental plots. Data were also collected at times at other Sea Island cotton locations.

Figure 1.--Locations of experimental cultivated and volunteer Sea Island cotton plots on St. Croix, U.S. Virgin Islands.

Daily maximum and minimum temperatures were recorded at a site about 91 m from the experimental cultivated cotton plots at the Kingshill Experiment Station.

Gossyplure-Baited Traps

Delta traps (Sandia Die and Cartridge Co., Albuquerque, N. Mex.), baited with 1 mg of gossyplure (1:1 mixture of _Z,E_ and _Z,Z_ isomers of 7,11 hexadecadienyl acetate) on rubber septa subtrates (Flint et al. 1974), were used throughout the studies. The traps were placed during June 1979 to December 1980 at all experimental cotton locations to study the seasonal distribution and abundance of St. Croix pink bollworm male moths on the island before and after start of releases of sterile moths, as well as to study dispersal and abundance of released sterile males. More gossyplure-baited traps were placed as shown in figure 2. Traps were inspected weekly

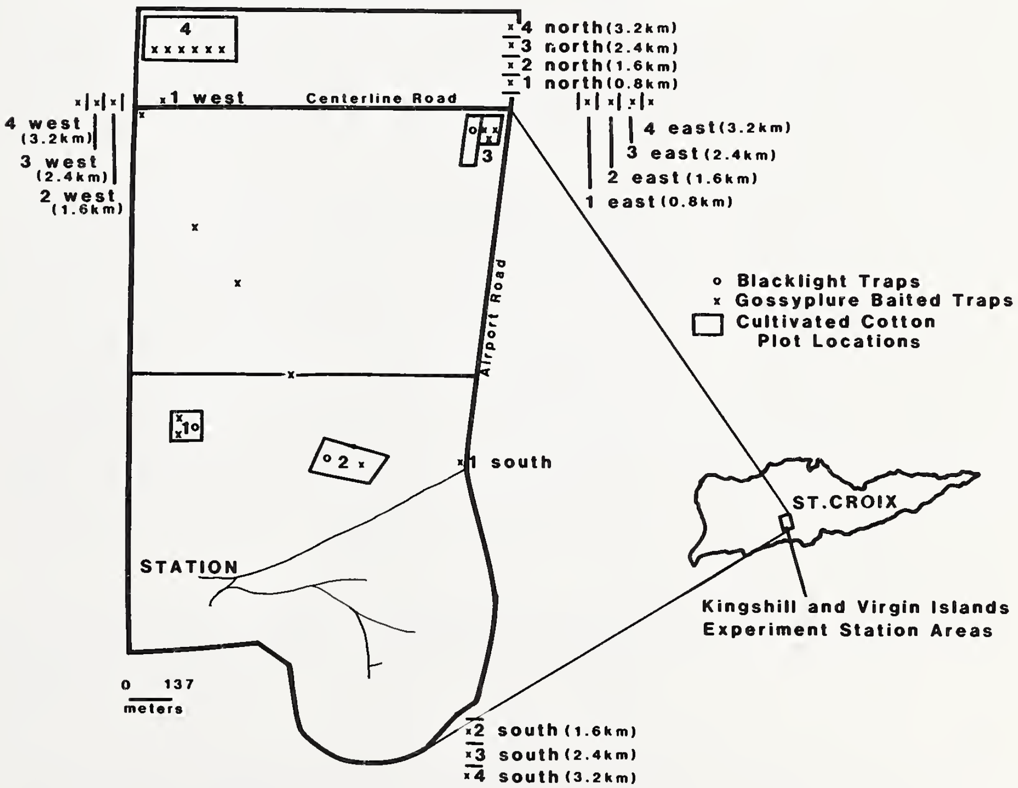

Figure 2.--Locations of gossyplure-baited Delta and blacklight traps. (Station = Kingshill Experiment Station.)

through March 17, 1981. Beginning March 18, 1981, gossyplure-baited traps in the sterile moth release plots were checked daily except on weekends.

Blacklight Traps

Three to four traps equipped with 15-W fluorescent blacklight lamps (Harding et al. 1966) were operated in cotton plots on the Kingshill Experiment Station from December 4, 1979, through May 1982 to collect pink bollworm moths for studies of the mating status of St. Croix and released sterile females. Traps were inspected at 1- to 3-day intervals until June 1980. Thereafter, except for weekends, traps were inspected and pink bollworm moths removed daily through May 1982. Collected females were dissected and examined for spermatophores.

Moth Irradiation and Shipment

Pink bollworm moths were mass-reared and irradiated (20-krad gamma radiation, Co^{60}-irradiator) in the adult stage at the APHIS pink bollworm rearing facility, Phoenix, Ariz. The rearing procedures, artificial diet, and handling procedures were as described by Mangum et al. (1969). The larval stages were reared in darkness. All other stages were maintained under simulated low light intensity of <0.02 foot-candle. The artificial diet of the mass-reared larvae contained Calco Red Oil dye. The dye incorporated in the larvae is carried through the pupae into the adult insect. So, released sterile insects could be distinguished from St. Croix insects.

Irradiated adult insects were placed in 13.3-cm-diameter by 1.9-cm-high circular cardboard containers with ventilated bottoms. Eight of these containers with moths (about 40,000) were placed in cylindrical, metal-lid cardboard canisters, 18.4-cm high by 14.0-cm in diameter. One canister was placed in each 27.3- by 19.1- by 26.7-cm-high FreezSafe polyfoam-insulated container with three newspaper-wrapped, 10.2- by 17.8- by 3.2-cm-high frozen Blue Ice gels for shipment. The insects were air-shipped to St. Croix 4 days weekly from December 28, 1980, through March 31, 1982, except for preliminary shipments (1,000/day) made on September 8-11, 15, 16, 18, and 19, 1980.

Upon arrival on St. Croix, moths were transferred from the shipping container to 25- by 35- by 5-cm-high porcelain trays. Samples of 100 moths were picked at random from the trays and the number of dead and live moths recorded. Moths (20) from each shipment were placed in each of three 273-cc containers and provided with 10-percent-sucrose solution for food. The containers with moths were held in an outdoor insectary for 14 days. Numbers of dead moths in each container were recorded daily. A sample of about 200 moths was placed in a 3,785-cc container (10-percent-sucrose solution food supplied). Twenty females were dissected on the day of arrival and 2 and 3 days

after arrival. They were examined for spermatophores to determine the percentages of mated, released females, as well as the ability of the insects to mate after shipment.

Sterile Moth Releases

Releases of sterile moths were made by hand in the cultivated cotton plots on the Kingshill and Virgin Islands Experiment Stations between the hours of 2 and 5 p.m. on the day received. Moths immobilized in a 4.4°C, walk-in refrigerator were loaded into 473-cc cylindrical cardboard containers with covers, carried to the cotton plots, and shaken from the containers. Numbers of released moths reported were corrected for deaths that occurred in transit from Phoenix to St. Croix.

From December 29, 1980, to April 7, 1981, releases of sterile moths were made in an experimental cotton plot at location 3 (figure 2) to study dispersal of the released sterile moths and their mating interactions with St. Croix moths. Releases of sterile moths from April 8, 1981, to April 1, 1982, were equally distributed in all cotton plots on Kingshill and Virgin Islands Experiment Stations.

Released sterile moths, as previously discussed, were from larvae reared on artificial diet containing Calco Red Oil dye, which was retained in the moths and identified released sterile moths from St. Croix moths. The potential use of the red dye as a spermatophore marker to measure the mating interaction of released mass-reared males and females with native moths was studied in the Western Cotton Research Laboratory, Phoenix, Ariz. Individual mass-reared, dyed or undyed virgin males were confined in 273-cc cylindrical cardboard containers with lids and provided 10-percent-sucrose solution as food. Two dyed or undyed virgin females were introduced into each cage. Females were removed in 24 hours and dissected. Spermatophores found were classified as red (male moths from larvae reared on dyed diet) or white (male moths from larvae reared on undyed diet). The procedure was repeated for four consecutive nights to obtain up to four sequentially produced spermatophores per male. Each treatment (dyed male with dyed females, dyed male with undyed females, undyed male with dyed females, and undyed male with undyed females) was replicated 6 to 10 times, and the experiment repeated 9 times.

Mating-Table Studies

Attractiveness and mating of mass-reared (irradiated and untreated), virgin female moths to St. Croix and released sterile males were studied using the mating-table techniques of Snow et al. (1976) and Lingren et al. (1979). St. Croix insects were obtained from infested bolls collected from Sea Island and cultivated cotton plots. The tables (1-3) were set in cotton plots at the Kingshill Experiment Station for

8 nights during the September 9 to 19, 1980, releases of sterile moths, and 29 nights during the December 29, 1980, to April 1, 1982, releases. Twenty clipped-wing, virgin, mass-reared (irradiated or untreated) or 20 clipped-wing St. Croix females were placed on individual tables at 12 p.m. Tables were checked at hourly intervals and mating pairs collected and recorded. At 6 a.m., all remaining moths were collected.

For 19 nights, during releases of sterile moths, mixtures of untreated St. Croix and untreated and irradiated mass-reared, clipped-wing, virgin females were confined on the same mating tables to compare attraction and mating of the strains under competitive conditions.

In all studies, clipped-wing females, collected as mating pairs and individually, were dissected and examined for the presence of spermatophores. Also, when females were collected in copula, males were identified and recorded as St. Croix or released sterile insects.

Collections of Moths in Sterile Moth Release Cotton Plots

During each night of the mating-table studies, male and female pink bollworm moths were collected by hand in the sterile moth release cotton plots during about 45 minutes of each hour from 12 p.m. to 6 a.m. using the methods described by Raulston et al. (1976) and Lingren et al. (1982). All insects collected were recorded as individuals or mating pairs, and females in both groups were dissected and examined for spermatophores from December 11, 1981, through March 25, 1982. St. Croix females only were dissected from January 15, 1981, to July 10, 1981.

Hourly Catches of Released Sterile Males in Gossyplure-Baited Traps

The distribution of male moth catches from midnight to 6 a.m. during the mating-table studies was determined by operating three to six gossyplure-baited traps in sterile moth release cotton plots. Traps were inspected at 1-hour intervals from 12 p.m. to 6 a.m., and the numbers of males caught were recorded at each interval.

Infestations in Cotton Flowers and Bolls

Total numbers of flowers in the cultivated cotton plots and on 10 plants at each of 5 Sea Island cotton locations and the numbers of infested (rosetted) flowers were counted weekly during flowering periods from January 1980 through May 1982.

Larval infestations in Sea Island cotton and cultivated cotton plots were determined by picking firm, immature cotton bolls and placing them in ventilated, plastic boxes as described by Fye (1976). Boxes were checked daily, adults were removed for 30 days, and the numbers of pink bollworms were recorded. Sampling was begun in January 1980 and continued through May 1982 at approximately weekly intervals when bolls were

available. On six occasions, October 7 and November 12, 1981, and February 5 and 23 and May 6 and 10, 1982, larvae or bolls containing larvae were collected and air-shipped to Phoenix. Male larvae were identified by the presence of purple-colored testes visible through the integument of the last instar. Cytological examinations of the testes were performed in the laboratory and the presence of chromosomal aberrations determined as described by Bartlett and Lewis (1973).

Data presented in this paper are those collected for all sampling categories from January 1, 1980, to June 30, 1982.

RESULTS

Experimental Cotton plots

Flowering curves for the five plantings of experimental cultivated cotton plots (sterile moth release plots) on the Kingshill and Virgin Islands Experiment Stations are shown in

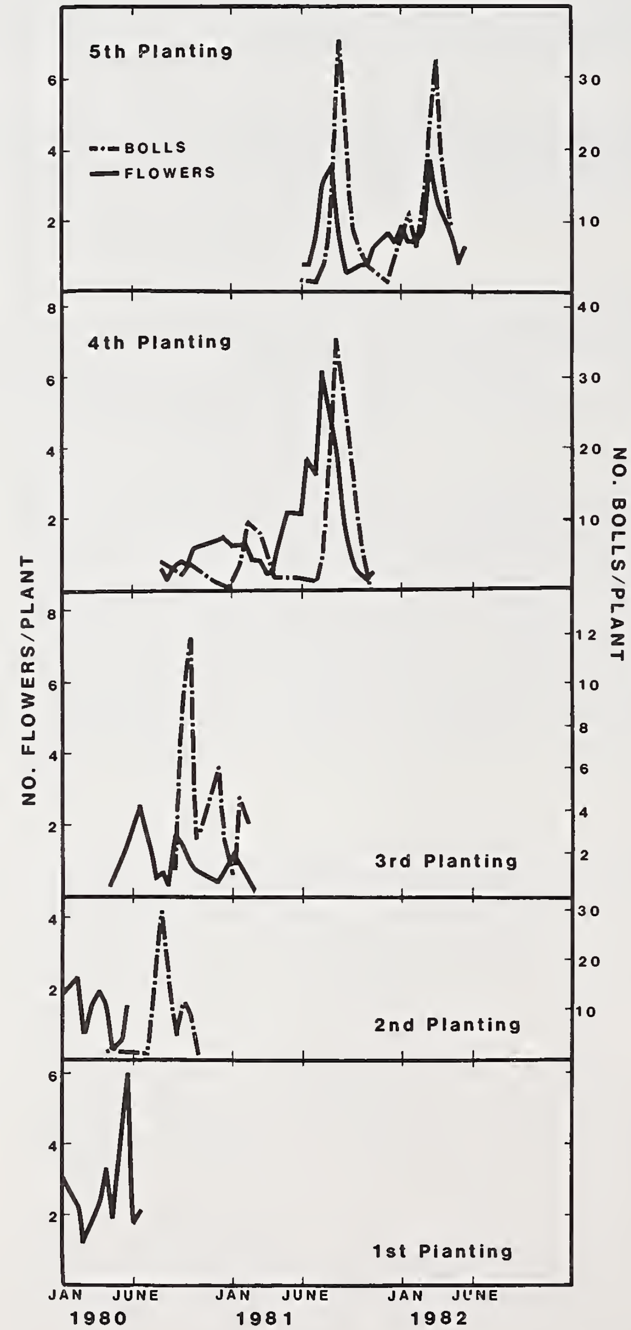

Figure 3.--Mean numbers of cotton flowers and bolls in cultivated cotton plots during release of sterile moths.

figure 3. Cotton plant development from seed planted at different dates provided host material (squares and bolls) for St. Croix pink bollworms in the sterile moth release plots during the entire experimental period. Generally, flowering in cultivated cotton plots outside the release area (controls) was more erratic, and fewer bolls developed per plant, due to lack of water (figure 4). Each year of the test, plants died in the control plots during May and June. Sea Island cotton flowered only during short days (<14 hours light) (figure 5). Peaks of flowering for the 1980-81 and 1981-82 growing periods occurred in early December and early February.

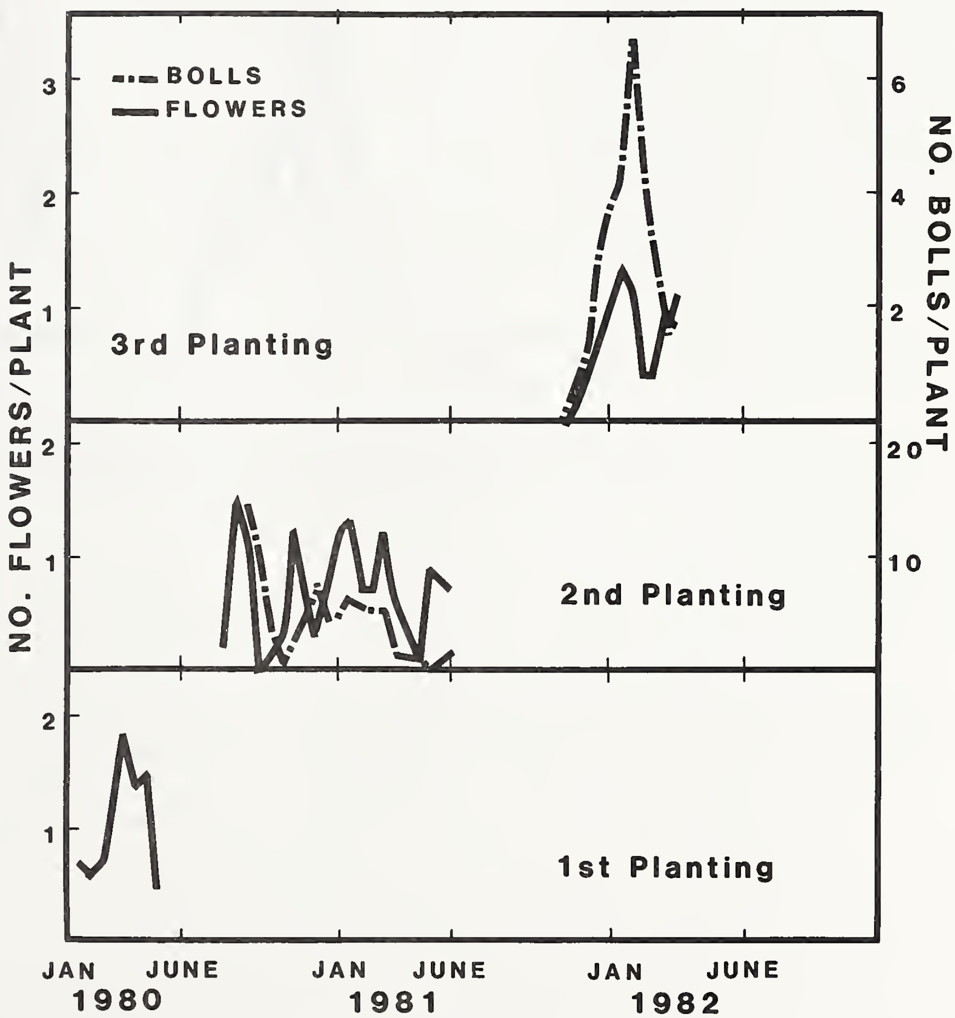

Figure 4.--Mean numbers of cotton flowers and bolls in the control cultivated cotton plots.

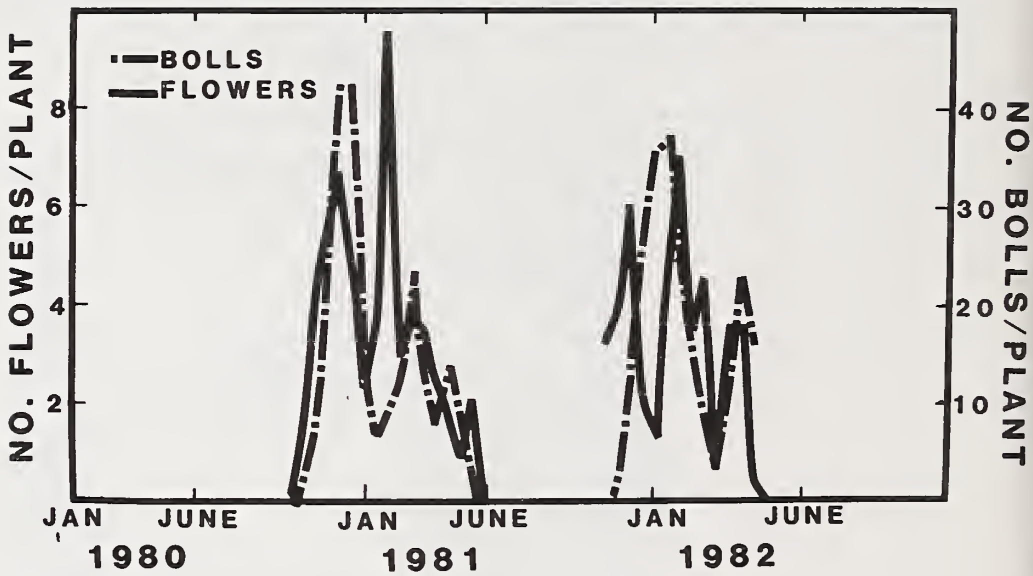

Figure 5.--Mean number of cotton flowers and bolls in Sea Island cotton plots, 1980-82.

During the experimental period from January 1, 1980, to May 31, 1982, daily minimum temperature ranged from 19° to 30°C and maximum temperatures from 27° to 32°C (table 1).

Table 1.--Mean[1] daily minimum and maximum temperatures on St. Croix during sterile pink bollworm release studies at Kingshill Experiment Station

Sampling period		Temperature (°C) in--					
		1980		1981		1982	
		Min.	Max.	Min.	Max.	Min.	Max.
Jan.	1-15......	23	28	21	29	23	28
	16-31.....	22	28	22	30	22	28
Feb.	1-15......	23	28	23	28	24	28
	16-28.....	19	27	23	28	22	27
Mar.	1-15......	22	28	23	29	23	28
	16-31.....	23	29	22	30	22	29
Apr.	1-15......	22	30	25	28	23	29
	16-30.....	22	31	25	29	23	30
May	1-15......	24	31	24	30	23	31
	16-31.....	24	31	24	29	24	30
June	1-15......	24	31	24	30	-	-
	16-30.....	25	32	25	31	-	-
July	1-15......	25	32	26	31	-	-
	16-31.....	26	32	25	32	-	-
Aug.	1-15......	26	31	26	32	-	-
	16-31.....	25	32	25	31	-	-
Sept.	1-15......	25	32	24	32	-	-
	16-30.....	30	31	25	32	-	-
Oct.	1-15......	29	31	24	32	-	-
	16-31.....	27	31	23	30	-	-
Nov.	1-15......	24	30	23	30	-	-
	16-30.....	27	30	25	31	-	-
Dec.	1-15......	24	28	23	29	-	-
	16-31.....	23	30	23	29	-	-

[1]Means of 6 to 8 readings per sampling period.

Moth Irradiation and Shipment

Mortality, in the insectary, of the irradiated, air-shipped, pink bollworm moths, arriving on St. Croix after 20 to 26 hours in transit, was 7±5 percent, whereas mortality of moths arriving after 40 to 56 hours in transit was 42±42 percent (table 2). Moths in transit over 56 hours arrived dead. Mortality, in 48 and 72 hours, of moths surviving 40 to 56 hours in transit was not significantly different from mortality of moths 20 to 26 hours in transit and ranged from 11 to 12 percent (48 hours) and 38 to 44 percent (72 hours). The regression analyses of the percentages of moth mortality for 14 days in the insectary, after receipt on St. Croix of moths in transit 20 to 26 and 40 to 56 hours, are shown in Figure 6.

Table 2.--Mean moth mortality and percentages of moths mated after airshipment from Phoenix to St. Croix, 1980-82

Hours moth shipments in transit	Number of shipments	Mortality (%) On arrival ±SD	Mortality (%) After (days)-- 7 ±SD	Mortality (%) After (days)-- 14 ±SD	Mated (%) On arrival ±SD	Mated (%) After (hours)-- 48 ±SD	Mated (%) After (hours)-- 72 ±SD
20 to 26.......	216	7±5	11±11	44±22	6±5	80±17	92±8
40 to 56.......	70	42±42	12±13	38±19	5±5	78±11	94±7
More than 56...	36	100	-	-	-	-	-

SD = standard deviation.

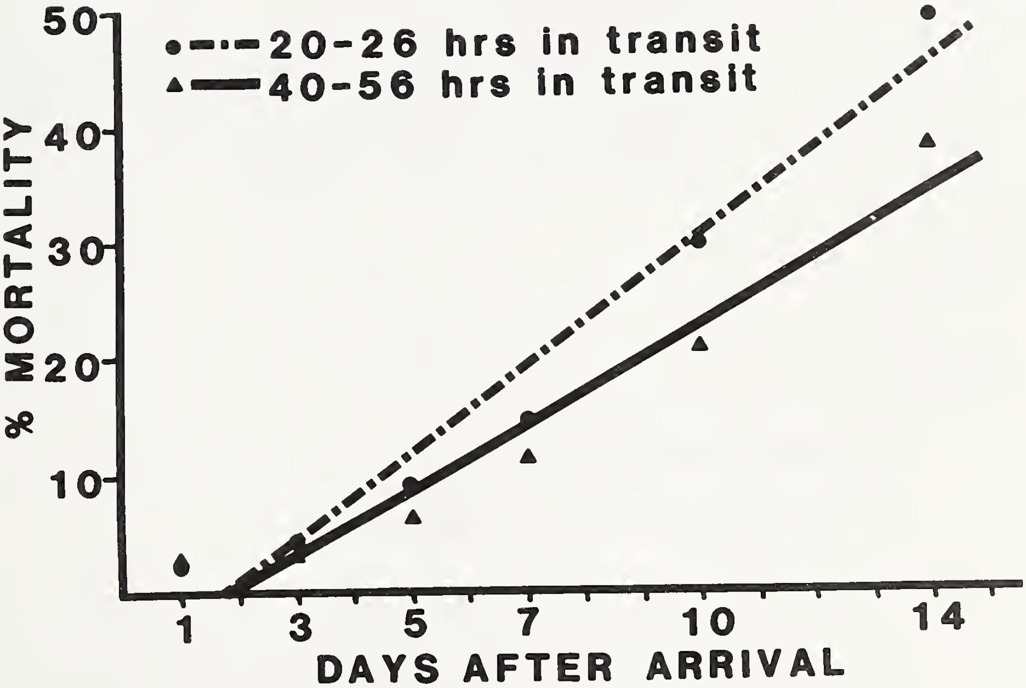

Figure 6.--Mean percentages of sterile moth mortality in the insectry for 1 to 14 days after shipment from Phoenix to St. Croix. $\hat{Y}$=-6.52+3.69X for moths 20 to 26 hours in transit (r=0.98), $\hat{Y}$=-4.74+2.79X for moths 40 to 56 hours in transit (r=0.97).

Moth mortality of released insects under field conditions was apparently higher than occurred in the insectary. On 19 occasions during the period from December 29, 1980, to March 31, 1982, no moth shipments, or high mortality in shipments, resulted in no sterile moth releases for 4- to 8-day periods. Numbers of released sterile male moths caught in gossyplure-baited traps each day after last releases during these occasions are shown in figure 7. Released sterile male moths were rarely captured more than 7 days after last releases. Over 40 percent of the total male moth captures during these periods occurred the first day after last releases. The percentages of released males captured thereafter decreased to less than 1 percent 7 days after last releases.

Percentages of mated females in shipments arriving after 20 to 26 and 40 to 56 hours in transit were 6±5 percent and 5±5 percent, respectively; and 78 to 94 percent of moths of both groups in the outdoor-insectary bioassay mated within 48 to 72 hours after arrival (table 2).

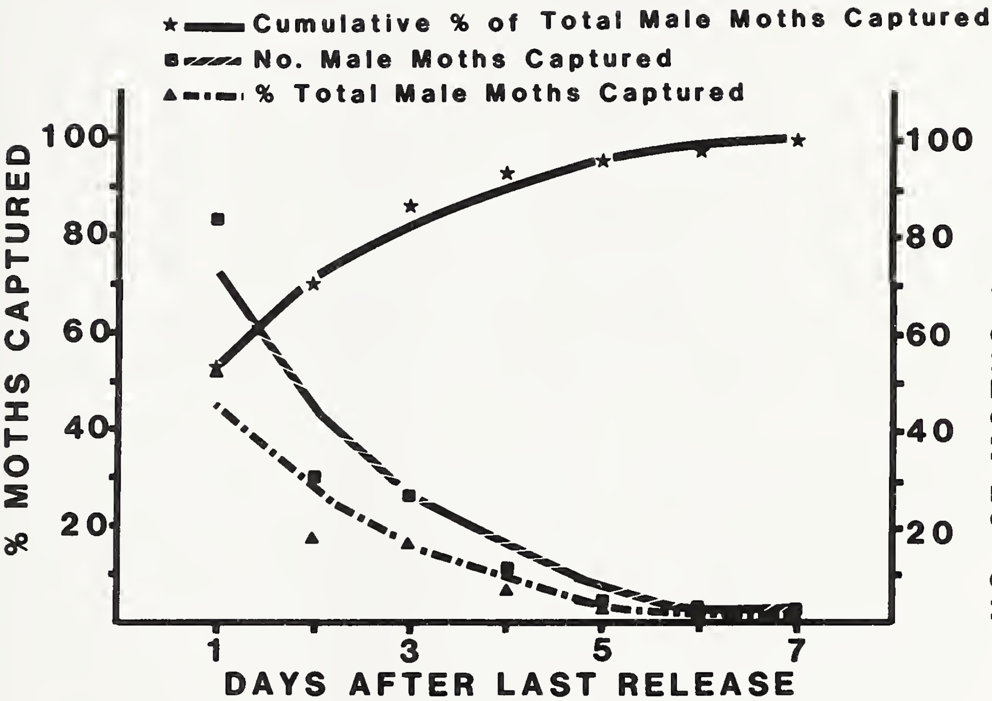

Figure 7.--Mean number, percentages, and cumulative percentages of total released sterile males that were caught 1 to 7 days after last moth releases were made.

Table 3.--Shipping, survival, and release data for sterile moths mass-reared in Phoenix and released on St. Croix, 1980-81

Release date	Number shipped	Mortality (%)	Total number of moths released	Estimated number of males released
Dec. 29	5,000	8	4,600	2,300
Jan. 13	5,000	28	3,600	1,800
14	5,000	0	5,000	2,500
Feb. 11	25,000	9	22,750	11,375
12	25,000	21	19,750	9,875
13	50,000	9	46,500	23,250
20	25,000	1	24,750	12,375
24	24,000	0	24,000	12,000
25	4,000	1	3,960	1,980
27	10,000	2	9,800	4,900
Mar. 3	20,000	5	18,950	9,475
4	10,000	6	9,400	4,700
6	20,000	22	15,500	7,750
10	15,000	34	9,900	4,950
11	10,000	53	4,650	2,325
17	55,000	8	50,600	25,300
18	55,000	27	40,150	20,075
19	55,000	19	44,550	22,275
20	55,000	38	34,100	17,050
23	55,000	10	49,500	24,750
24	55,000	18	45,100	22,550
25	55,000	13	47,850	23,925
27	110,000	5	104,450	52,225
30	55,000	3	53,350	26,675
31	55,000	4	52,800	26,400
Apr. 1	55,000	1	54,450	27,225
2	55,000	3	53,350	26,675
3	55,000	3	53,350	26,675
6	55,000	3	53,350	26,675
7	46,000	8	42,320	21,160
Total..	1,124,000	12.1[1]	1,002,380	501,190

[1]Average percent mortality for all shipments.

Sterile Moth Releases

Releases of 3,600 to 104,450 sterile moths per day (table 3) were made from December 29, 1980, to April 7, 1981, in a cotton plot at location 3 (fig. 2) on the Kingshill Experiment Station to study sterile moth dispersal. Gossyplure-baited traps caught about 0.6 percent (2,779) of the released sterile

Table 4.--Mean numbers and percentages of released sterile males caught per gossyplure-baited trap, 1980-81[1]

Distance from release plot (km)	Number captured Total	Number captured Per trap	Total caught (%)
0.0[2]	2,231	744	80.3
.8	504	32	18.1
1.6	23	6	.8
2.4	7	2	.3
3.2	14	4	.5
2.8-18.4[3]	0	0	.0
Total	2,779	788	100.0

[1]Numbers released and dates shown in table 3.
[2]Male moths captured in the release cotton plot.
[3]Traps located at all other locations, figure 1.

males (table 4). Most (98 percent) of the released sterile males were captured in the release plot or in traps within 0.8 km distance from the release plot (fig. 8). Small percentages of the released males were captured between 1.6 and 3.2 km from the release location. No released sterile males were captured in traps distributed in Sea Island cotton 3 to 20 km from where the moths were released.

Assuming that moths moved from the release plots in all directions, the probability of their being captured decreased in relation to the increasing area from the point of release, so more moths probably dispersed from the release site than is indicated from the results.

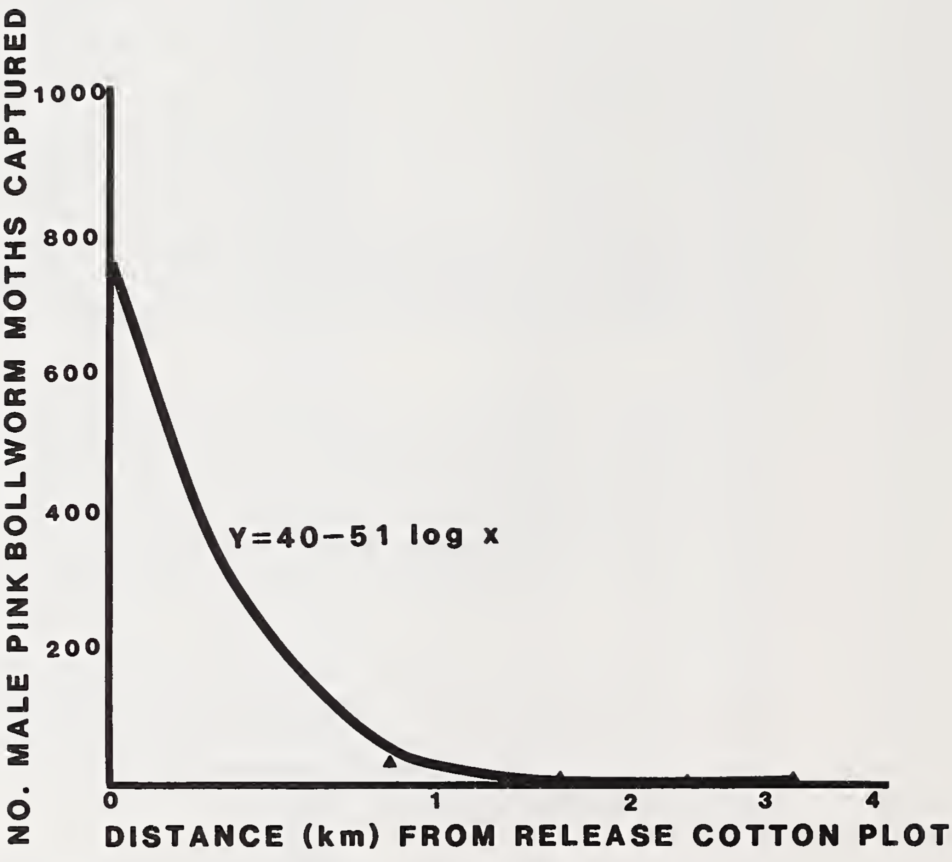

Figure 8.--Total number of released sterile males captured at the release location and at 0.8, 1.6, 2.4, and 3.2 km from the release site, and estimated numbers based on increasing areas and decreasing probability of male moth captures within distance from the release site.

Table 5.--Total numbers and percentages of released sterile moths captured in blacklight traps, 1980-81

Distance from release plot (km)	Total number[1]		Percent of total captured	
	Males	Females	Males	Females
0.0[2]	465a	517a	98	98
.8	11a	12a	2	2
Total	476a	529a	100	100

[1]Numbers within rows followed by the same letter are not significantly different by Duncan's (1955) multiple-range test (t-test, $P=0.05$).
[2]Moths captured in the release plot.

There were no statistically significant differences between the numbers of released males and females captured in blacklight traps (table 5). Most (98 percent) of each sex were captured in the release plot, but 2 percent of both released sterile males and females were captured in blacklight traps 0.8 km from where the insects were released.

The numbers of days sterile moths were released, total number released, and percentages of released male moths caught in gossyplure-baited traps from December 29, 1980, to April 1, 1982, are shown in table 6. Percentages of released sterile moths caught assume equal numbers of males and females released and are calculated and tabulated on the basis of the actual number of traps operating during the appropriate sampling period and also on the basis of a standardized sterile male moth catch per 100 traps (mean/trap/day ÷ actual number of traps X 100). The numbers of released sterile males captured in gossyplure-baited traps were highly correlated to the number of traps operating ($r=0.75$, $\hat{Y}=0.004\pm^{2.62}$) and to the number of released sterile males ($r=0.87$, $\hat{Y}=16.4\pm^{1.03}$) during the sampling periods.

In 1980, before the start of large-scale, sterile moth releases, St. Croix male moth trap catches in cultivated cotton plots on the Kingshill and Virgin Islands Experiment Stations were significantly higher than in cultivated cotton plots off the station or in Sea Island cotton (table 7). Male moths were caught every month of the year in cultivated cotton plots on the experiment stations and in Sea Island cotton. Traps in cultivated cotton (control) plots off the station were removed when the plants died due to drought in late May 1980 and replaced in newly planted plots in January 1981.

Table 6.--Sterile moths released and males caught in gossyplure-baited traps in cultivated cotton plots

Release period		Number of-- Days released	Sterile moths released[1] (1,000's)	Total number of-- Gossyplure-baited traps	Sterile males caught	Males caught (%)[2] Per[3] 100 traps	In all traps
1981							
Jan.	1-15	3	13.2	87	55	1.0	0.8
	16-31	0	-	108	141	2.0	2.0
Feb.	1-15	3	87.0	90	572	1.5	1.3
	16-28	4	67.5	87	651	2.2	1.9
Mar.	1-15	5	58.5	96	472	1.7	1.6
	16-31	10	581.0	176	425	.2	.3
Apr.	1-15	10	426.9	182	573	.2	.3
	16-30	7	314.6	182	2,681	.9	1.7
May	1-15	10	466.7	175	7,752	1.9	3.3
	16-31	8	978.9	193	17,318	1.8	3.5
June	1-15	9	888.9	213	16,652	1.8	3.7
	16-30	8	779.9	222	19,603	2.3	5.0
July	1-15	8	754.9	162	10,438	1.7	2.7
	16-31	11	1,276.9	315	24,271	1.2	3.8
Aug.	1-15	9	982.9	505	15,721	.6	3.2
	16-31	11	1,229.4	287	17,611	1.0	2.9
Sept.	1-15	7	441.2	217	5,811	1.2	2.5
	16-30	8	413.4	267	10,597	1.9	5.1
Oct.	1-15	8	740.8	222	3,482	.4	.9
	16-31	8	893.5	135	5,730	1.0	1.3
Nov.	1-15	6	584.0	168	8,690	1.8	2.9
	16-30	5	564.0	183	8,523	1.7	3.0
Dec.	1-15	9	960.0	257	10,756	.9	2.2
	16-31	6	545.0	278	8,087	1.1	3.0
1982							
Jan.	1-15	3	379.0	299	3,929	.7	2.0
	16-31	7	168.0	334	4,908	1.8	5.8
Feb.	1-15	7	1,632.0	314	11,482	.5	1.4
	16-28	5	1,222.0	279	5,277	.3	.9
Mar.	1-15	7	1,766.0	270	8,033	.3	.9
	16-31	13	2,865.0	309	13,236	.3	.9
Apr.	1-15[4]	1	180.0	292	1,812	2.0	2.0
Total.....		216	22,261.1	6,904	245,209	-	-
Mean		-	103[5]	222.7		1.2	2.3

[1]Includes 4,600 sterile moths released on December 29, 1980.
[2]Assumes equal numbers of males and females released.
[3]No. caught ÷No. traps in operation X100 ÷No. males released X100.
[4]Last release: April 1, 1982.
[5]Mean number of released sterile moths per release day.

Table 7.--St. Croix males caught per gossyplure-baited trap per night in all plots before releases started[1] in 1980

Sampling period		Mean[2] number of St. Croix males caught in--		
		Cultivated cotton		Sea Island cotton
		Release plots	Control plots	
Jan.	1-15	19.9a	1.0b	1.4b
	16-31	15.8a	1.0b	1.6b
Feb.	1-15	12.0a	2.0b	1.3b
	16-28	10.7a	1.1b	1.0b
Mar.	1-15	13.5a	1.3b	1.4b
	16-31	20.4a	1.2b	1.9b
Apr.	1-15	11.0a	1.6b	1.5b
	16-30	7.0a	1.7b	.7b
May	1-15	10.0a	2.0b	1.4b
	16-31	4.4a	-	.9b
June	1-15	6.9a	-	.6b
	16-30	7.3a	-	.4b
July	1-15	6.8a	-	.5b
	16-31	14.1a	-	.5b
Aug.	1-15	16.5a	-	.4b
	16-31	20.1a	-	.5b
Sept.	1-15[3]	10.3a	-	.2b
	16-30	5.8a	-	.3b
Oct.	1-15	9.0a	-	.4b
	16-31	10.0a	-	.5b
Nov.	1-15	13.1a	-	1.0b
	16-30	11.6a	-	.6b
Dec.	1-15	10.4a	-	.7b
	16-31	7.0a	-	1.0b

[1]Sustained releases of sterile moths started December 29, 1980. Release on the Kingshill and Virgin Islands Experiment Stations. An earlier release was made September 9-19 in the release plots.

[2]Means of 6 to 66 observations per sampling period. Means within rows on the sampling periods not followed by the same letter are significantly different by Duncan's (1955) multiple-range test (*P*=0.05).

[3]From 9,000 moths released September 9-19, 1980, 41 released sterile males were recovered from September 9 through 15; 1 was recovered from September 16 through 30.

In early January 1980, 20 St. Croix males were caught per trap per night in cultivated cotton on the two experiment stations (table 7). The numbers varied thereafter with low numbers caught in late spring and early summer. Male moth catches in Sea Island cotton followed similar trends, but lower numbers were caught. A total of 42 (0.9 percent) released sterile males were recovered in gossyplure-baited traps after the September 9 to 19, 1980, releases (1,000/day, 9 releases). All captures of released sterile males were in gossyplure-baited traps in the release plots.

Table 8.--St. Croix (N) and released sterile (S) males caught per gossyplure-baited trap per night in all plots, 1981

Sampling period		Mean number[1] moths caught in--				
		Cultivated cotton				
		Release plots			Control plots,	Sea Island cotton,
		St. Croix males	Sterile males	S:N ratio	St. Croix moths	St. Croix moths
Jan.	1-15	4.1a	0.3	0.1:1	0.2b	1.1b
	16-31	4.2a	.6	.1:1	1.2b	1.4b
Feb.	1-15	4.9a	15.0	3.1:1	1.0b	1.1b
	16-28	5.3a	10.6	2.0:1	[2]1.0b	[2]1.0b
Mar.	1-15	4.9a	4.7	.1:1	.7b	[2]1.5b
	16-31	4.2a	3.1	.7:1	.7b	1.7b
Apr.	1-15	3.6a	2.4	.7:1	1.0b	.5b
	16-30	2.7a	4.9	1.8:1	.9b	1.0b
May	1-15	1.5a	31.3	20.9:1	[2]1.0a	[2]1.7a
	16-31	1.0b	94.2	94.2:1	1.1b	[2]2.2a
June	1-15	1.4a	61.4	43.9:1	[2]1.5a	1.6a
	16-30	1.0a	97.9	97.9:1	.8a	[2]1.7a
July	1-15	1.2a	45.9	38.3:1	.1a	1.0a
	16-31	.5a	56.2	112.4:1	.0a	[2]1.0a
Aug.	1-15	.3a	28.2	94.0:1	.2a	.3a
	16-31	.5a	37.9	75.8:1	.1b	.2ab
Sept.	1-15	1.1a	11.3	10.2:1	[2].0b	[2].2b
	16-30	1.0a	25.7	25.7:1	.5b	[2].3b
Oct.	1-15	.4a	11.7	29.3:1	-	.2b
	16-31	.3a	22.1	73.6:1	-	.1a
Nov.	1-15	.6a	41.8	69.6:1	.4a	.2a
	16-30	.5b	29.0	58.0:1	6.1a	1.3b
Dec.	1-15	.7a	36.5	52.1:1	.1a	[2]1.2a
	16-31	.9a	28.1	31.2:1	[2].3a	1.3a

[1]Means of 4 to 107 observations per sampling period. Means within rows for St. Croix moths not followed by the same letter are significantly different by Duncan's (1955) multiple range test ($P=0.05$).
[2]Means of <0.1 sterile-released male moth per trap per night caught during indicated sampling period in plots <3 km from sterile moth release area.

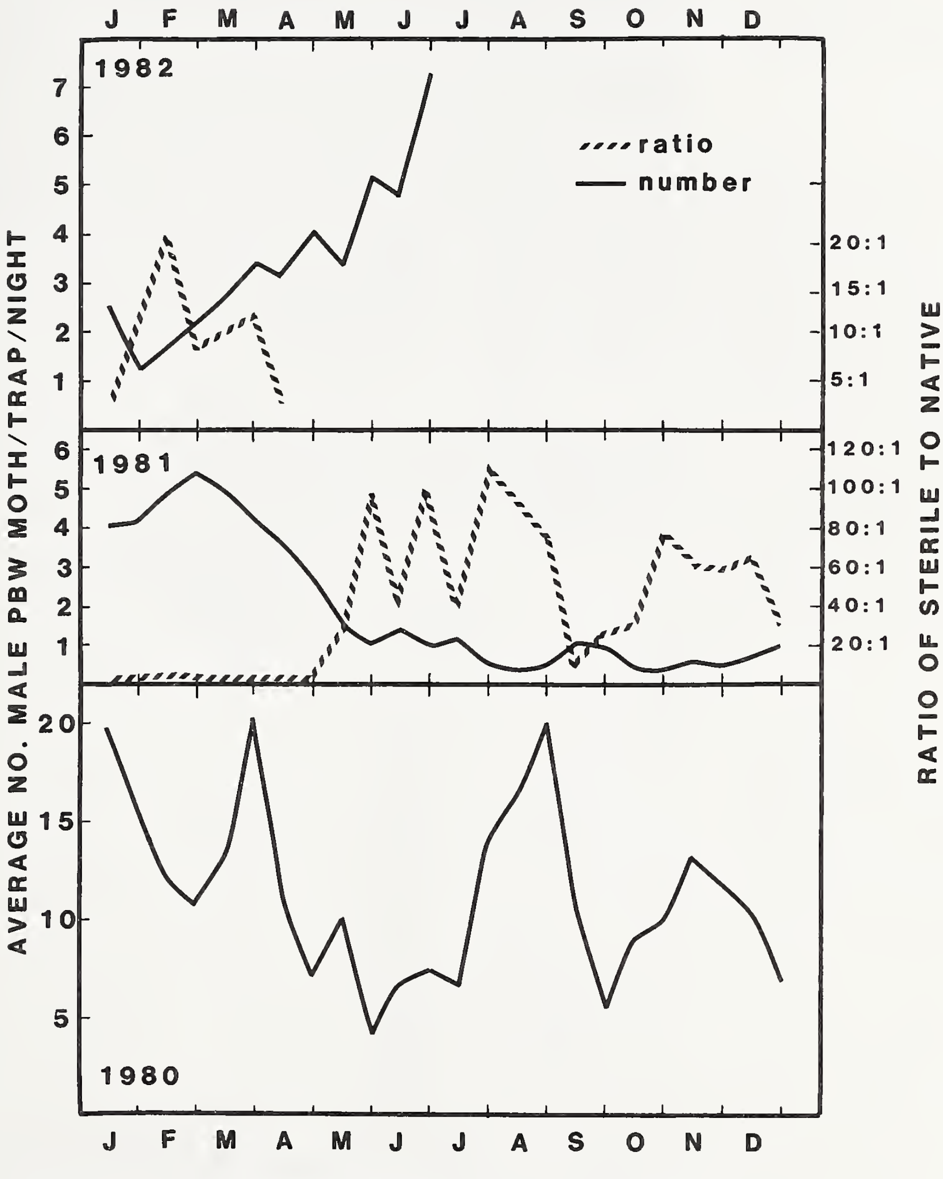

Figure 9.--Average numbers of St. Croix males per trap per night and the ratio of released sterile males to St. Croix males in gossyplure-baited traps, 1980-82 (catches in 1980 before start of large-scale, sterile moth releases).

After the start of large-scale releases of sterile moths on December 29, 1980, St. Croix male moth catch trends from January through April in 1981 in the release plots remained high (table 8, fig. 9). But, with increasing ratios of released sterile males to St. Croix males caught in gossyplure-baited traps from May through December, numbers of St. Croix males caught ranged from 0.3 to 1.5 per trap per night, although only the collections of May 16 to 31 and November 16 to 30 were significantly different from other periods. When ratios of released sterile males to St. Croix males decreased during mid-February through March 1982, numbers of St. Croix males caught increased (table 9, fig. 9). Numbers of St. Croix males caught in gossyplure-baited traps

Table 9.--St. Croix (N) and released sterile (S) males caught per gossyplure-baited trap per night[1] in all plots in 1982

	Cultivated cotton				
	Release plots			St. Croix moths	
Sampling date	St. Croix male moths	Sterile male moths	S:N Ratio	Control plots	Sea Island cotton
Jan. 1-15	2.5b	10.9	4.4:1	[2]0.4	1.2a
16-31	1.2a	13.0	10.8:1	.4a	[3]1.7a
Feb. 1-15	1.7a	33.1	19.5:1	[3]1.4a	[3]2.0a
16-28	2.2a	18.8	8.6:1	2.6a	2.3a
Mar. 1-15	2.7a	27.5	10.2:1	2.5a	2.1a
16-31	3.4a	39.0	11.5:1	2.3	2.0a
Apr. 1-15	3.2a	[4]5.5	1.7:1	[3]1.8a	2.1a
16-30	4.1a	0	-	.6b	1.0b
May. 1-15	3.4a	0	-	.3b	1.2b
16-31	5.2a	0	-	.4c	1.4b
June 1-15	4.8a	0	-	.4c	1.4b
16-30	7.3a	0	-	.5b	1.2b

[1]Means of 4 to 107 observations per sampling period. Means within rows for St. Croix moths not followed by the same letter are significantly different by Duncan's (1955) multiple-range test ($\underline{P}$=0.05).
[2]Sustained release of sterile moths initiated December 29, 1980.
[3]Means of <0.1 sterile release male moth per trap per night caught during indicated sampling period in plots <3 km from the sterile moth release area.
[4]Last sterile moth release, April 1, 1982.

were negatively correlated ($\underline{r}$=0.87) to the ratio of sterile to St. Croix males in the traps, whereas the numbers of St. Croix males caught in blacklight traps were poorly correlated ($\underline{r}$=0.06) to the ratios of sterile to St. Croix males caught in gossyplure-baited traps or of sterile to native males in blacklight traps ($\underline{r}$=0.06).

These results suggest that reduced catches of St. Croix males during the sterile moth releases were not good indicators of the impact of the sterile moth releases on reproduction of the pink bollworm population. Since both sterile males and females were released, possibly the large number of sterile females in the population was in direct competition with gossyplure-baited traps in attracting St. Croix males. St. Croix male moth catches increased after the last release of sterile moths on April 1, 1982. St. Croix male moth catches in control cultivated cotton plots outside the release area were low from January through September 1981. A peak catch of 6.1 males per trap per night occurred in late November 1981, decreasing thereafter during January and February, and increasing in late February through March, followed by a decrease thereafter through June. Male moth catches in Sea Island cotton were low, ranging from 0.1 to 2.3 males per trap per night from January 1981 through June 1982.

Average ratios of sterile to St. Croix males caught in gossyplure-baited traps were less than 1:1 from January through April 1981 but increased fom 21:1 to 98:1 in the June 16 to 31 sampling period, averaging 72:1 from May 1 to August 31. Ratios of sterile to St. Croix males decreased to an average of 21.7 in September to mid-October because of delayed airline deliveries or poor handling at points of origin and receiving, which resulted in high sterile moth mortalities and reduced numbers of sterile moth releases (table 8). Ratios of sterile to St. Croix males averaged 52.7 in November and December. Thereafter, ratios through March 31, 1982, averaged only 11:1 (table 9). Released sterile males were caught on relatively few sampling dates and in low numbers (<0.1 per trap per night) only in cultivated cotton plots (during 7 of 36 sampling periods), off the station, and in gossyplure-baited traps placed in Sea Island cotton (during 11 of 36 sampling periods) less than 3 km from the sterile moth release area.

The results of the laboratory studies at Phoenix to determine the potential as a spermatophore marker of the Calco Red Oil dye incorporated in the artificial diet are shown in table 10. The white spermatophores from males from larvae reared on undyed artificial diet (U) mated to females from larvae reared on dyed artificial diet (R) were contaminated with the dye

incorporated in the females in about 40 percent of the matings (table 10). About 88 percent of the first spermatophores from R males mated with U females were identifiable as red. However, percentages of identifiable red-dyed spermatophores decreased thereafter with each sequential mating. The spermatophores from R moth mating pairs were identifiable as red in 79 percent of the matings, and spermatophores from U moth mating pairs were white 100 percent of the time.

Table 10.--Spermatophores produced sequentially by males from larvae reared on artificial diet containing Calco Red Oil dye (R) or no dye (U) after mating with females from larvae reared on dyed or undyed artificial diet

Mating combination and number of sequentially produced spermatophores: Male	Female	Mean percent males producing indicated spermatophore	Total spermatophores: Red	White	Mean percent of red spermatophores
U	U (50)[2]				
1		100	0	50	0
2		91	0	45	0
3		65	0	32	0
4		30	0	15	0
U	R (54)				
1		100	22	32	41
2		81	11	32	26
3		57	13	18	42
4		26	7	7	50
R	R (55)				
1		100	50	5	91
2		87	35	13	70
3		63	27	7	79
4		31	13	4	76
R	U (56)				
1		98	49	7	88
2		84	29	16	64
3		53	18	12	60
4		32	2	14	13

[1]Means of 50 to 56 individual males.
[2]Numbers in parentheses are the numbers of individual males in each mating combination.

Blacklight Trap Collections

St. Croix male moth trap catches in blacklight traps in 1980 followed monthly trends (table 11) similar to those reported for gossyplure-baited traps. More males than females were caught in blacklight traps (average for all sampling periods 3.8 vs. 1.8 per trap per night). Percentages of mated St. Croix females caught in blacklight traps ranged from 33 to 100 percent, and numbers of spermatophores per female ranged from 1.0 to 3.0

Table 11.--St. Croix males and females caught in blacklight traps from cotton plots on the Kingshill Experiment Station in 1980 (before sustained releases of sterile moths) and mating data for females

Sampling period		Mean[1] No./trap/night		Females		Spermatophoes/mated female
		Males	Females	Total collected	Percent mated	
Jan.	1-15	2.0	2.9	15	73	1.2
	16-31	.0	.5	1	100	1.0
Feb.	1-15	3.1	.6	12	75	1.0
	16-28	.2	.3	3	33	1.0
Mar.	1-15	.4	.6	20	85	1.1
	16-31	.2	.7	23	96	1.3
Apr.	1-15	1.0	.9	44	93	1.5
	16-30	.9	1.7	26	81	1.9
May	1-15	1.1	.8	34	85	1.2
	16-31	3.5	1.8	59	80	1.3
June	1-15	2.6	1.2	25	80	1.5
	16-30	.4	0	0	-	-
July	1-15	1.7	.5	4	75	3.0
	16-31	6.6	1.5	41	93	2.4
Aug.	1-15	6.2	3.0	72	87	1.9
	16-31	7.8	2.4	40	87	1.6
Sept.	1-15	5.8	1.4	38	92	2.3
	16-30	[2]3.1	1.2	26	85	[3]2.1
Oct.	1-15	5.8	2.4	76	89	1.7
	16-31	8.7	3.9	96	86	1.9
Nov.	1-15	17.6	8.1	145	79	1.6
	16-30	4.6	3.5	101	82	1.5
Dec.	1-15	2.7	1.3	20	85	1.6
	16-31	4.1	1.0	22	91	1.9

[1]Means of 2 to 4 blacklight traps.
[2]0.8 released sterile male per trap/night caught September 13 to 23.
[3]One released sterile female caught September 11 to 30 with 1 spermatophore.

Significantly more St. Croix males were caught in gossyplure-baited than in blacklight traps during all sampling periods except November 1 to 15 when males caught in blacklight traps averaged 18 per trap per night compared with 13 per trap per night in gossyplure-baited traps. The average numbers of St. Croix males per trap per night caught in gossyplure-baited traps and blacklight traps, for all sampling periods in 1980, were 11.4 and 3.8, respectively.

Catches of St. Croix males in January 1981, after the start of large-scale sterile moth releases (December 29, 1980), averaged 3.6 males per trap per night (table 12). Numbers of St. Croix males caught were low through mid-July, increasing thereafter to an average of 8.4 per trap per night in September, then decreasing to a low average of 0.1 per trap per night from February 1 to 15, 1982. Numbers caught remained low through March but increased after the end of releases of sterile moths. No released sterile males or females were caught in blacklight traps in January 1981. Captures of released sterile moths increased to peaks of 115.6 and 49.0 males and females, respectively, per trap per night during September 16 to 30, 1981. Numbers of released sterile moths caught decreased thereafter through March 1982.

Of the St. Croix females caught in blacklight traps through April 15, 1981, 62 to 83 percent were mated, but no red spermatophores from released sterile male moths were found (table 13). From April 16 to 30, 1981, to March 16 to 31, 1982, St. Croix females were found that had mated with released sterile males on all but 3 of the 20 sampling dates. Percentages of released sterile male to St. Croix female matings ranged from 17 to 57 percent as measured by the presence of red spermatophores. The actual percentages of released sterile male to St. Croix female mating may have been higher than recorded since released sterile males do not transfer a red-dyed spermatophore in all matings. Of the blacklight-captured, released sterile females during this period, 12 to 60 percent had mated and contained 0.9 to 3.0 spermatophores per mated female.

Sterile to St. Croix Ratios in Traps, and Expected vs. Observed Sterile Matings

From January 1 to October 15, 1981, the numbers of red spermatophores from released sterile males and white spermatophores from St. Croix males were determined in St. Croix females caught in blacklight traps. Sterile St. Croix male moth ratios in gossyplure-baited and blacklight traps varied from 0.1 to 112.4 and 0.1 to 41.4:1, respectively (table 14). Expected numbers of released sterile male to St. Croix female matings, assuming released males were fully competitive with St. Croix males in obtaining St. Croix female mates, ranged from <1 to 31 for gossyplure-baited trap ratios and <1 to 26

Table 12.--St. Croix and released sterile males and females captured per night per blacklight trap in cotton plots

Sampling period		Mean number of male moths		Sterile ♂: St. Croix ♂ ratio	Mean number of female moths		Sterile ♀: St. Croix ♀ ratio
		St. Croix	Released sterile		St. Croix	Sterile	
1981							
Jan.	1-15	5.3	0	0	1.1	0	0
	16-31	2.0	0	0	1.3	0	0
Feb.	1-15	1.4	0.1	0.1:1	.9	0	0
	16-28	.9	1.2	1.31:1	.3	0.2	0.7:1
Mar.	1-15	1.9	.9	.5:1	1.1	.6	.5:1
	16-31	.7	14.5	20.7:1	.3	19.7	65.7:1
Apr.	1-15	.7	7.3	10.4:1	1.2	8.5	7.1:1
	16-30	.7	1.2	1.7:1	.4	.7	1.8:1
May	1-15	.6	8.2	13.7:1	.6	2.3	3.8:1
	16-31	1.5	24.0	16.0:1	.8	10.4	13.0:1
June	1-15	.4	13.5	33.8:1	.9	4.1	4.6:1
	16-30	.5	14.1	28.2:1	.3	3.4	11.3:1
July	1-15	.6	19.4	32.3:1	.9	4.4	4.9:1
	16-31	1.7	37.1	21.8:1	1.5	5.2	3.5:1
Aug.	1-15	1.4	57.9	41.4:1	.4	11.7	29.3:1
	16-31	2.9	92.3	31.8:1	.9	18.7	20.8:1
Sept.	1-15	8.4	69.1	8.2:1	5.1	19.5	3.8:1
	16-30	8.1	115.6	14.3:1	7.2	49.0	6.8:1
Oct.	1-15	6.8	43.3	6.4:1	6.7	15.5	2.3:1
	16-31	4.4	66.9	15.2:1	2.8	13.7	4.9:1
Nov.	1-15	4.3	78.2	18.2:1	3.7	27.2	7.4:1
	16-30	2.1	28.0	13.3:1	1.3	13.2	10.2:1
Dec.	1-15	1.5	35.1	23.4:1	1.1	15.5	14.1:1
	16-31	.9	9.5	10.6:1	.3	2.0	6.7:1
1982							
Jan.	1-15	.2	9.1	45.5:1	.2	3.6	18.0:1
	16-31	.6	3.2	5.3:1	.3	1.1	3.7:1
Feb.	1-15	.1	1.7	17.0:1	.3	.6	2.0:1
	16-28	.4	5.5	13.8:1	.1	5.4	54.0:1
Mar.	1-15	.5	2.6	5.2:1	.2	1.2	6.0:1
	16-31	.7	6.3	9.0:1	.5	1.7	3.4:1
Apr.	1-15	1.4	1.1	.8:1	.9	.5	.6:1
	16-30	1.0	0	-	1.4	0	-
May	1-15	4.7	0	-	2.7	0	-
	16-31	5.8	0	-	5.8	0	-

Table 13.--St. Croix and released sterile females caught in blacklight traps and mating data

Sampling period		St. Croix female moths					Sterile female moths				
		Number collected	Percent mated	Spermatophores/ mated female	Percent mated with-- St. Croix males	Percent mated with-- Sterile males	Number collected	Percent mated	Spermatophores/ mated female	Percent mated with-- St. Croix males[1]	Percent mated with-- Sterile males[2]
1981											
Jan.	1-15	18	72	1.3	100	0	0	-	-	-	-
	16-31	30	83	2.0	100	0	0	-	-	-	-
Feb.	1-15	21	81	1.8	100	0	0	-	-	-	-
	16-28	8	75	1.2	100	0	5	60	3.0	-	-
Mar.	1-15	50	62	1.6	100	0	41	24	1.0	-	-
	16-31	21	76	1.4	100	0	375	29	1.2	-	-
Apr.	1-15	29	62	1.3	100	0	141	33	1.1	-	-
	16-30	8	100	1.5	75	25	8	12	1.0	-	-
May	1-15	12	92	1.6	83	17	64	33	1.1	-	-
	16-31	15	60	1.3	100	0	209	42	1.6	-	-
June	1-15	11	12	2.0	75	25	44	27	1.8	-	-
	16-30	2	100	2.0	50	50	33	24	1.5	-	-
July	1-15	11	91	2.4	48	42	36	31	1.5	-	-
	16-31	18	67	1.8	68	32	84	48	1.4	-	-
Aug.	1-15	6	33	1.0	100	0	142	34	1.2	-	-
	16-31	15	73	2.0	50	50	302	29	1.3	-	-
Sept.	1-15	134	85	2.0	67	33	482	26	1.3	-	-
	16-30	199	59	1.5	66	34	975	26	1.3	-	-
Oct.	1-15	203	47	1.6	81	19	416	26	1.2	-	-
	16-31	89	49	1.7	66	34	348	21	1.1	31	69
Nov.	1-15	114	65	2.1	50	50	831	42	1.4	12	88
	16-30	38	74	1.8	43	57	396	48	1.3	14	86
Dec.	1-15	34	65	1.1	71	29	460	18	1.4	10	90
	16-31	9	44	1.8	86	14	55	49	1.3	0	100
1982											
Jan.	1-15	6	83	2.2	73	27	140	44	1.2	3	97
	16-31	12	83	1.2	83	17	43	49	1.0	3	97
Feb.	1-15	9	78	1.4	100	0	26	54	1.2	4	89
	16-28	4	75	1.3	67	33	192	41	1.0	5	95
Mar.	1-15	9	67	2.2	46	54	41	54	1.1	0	100
	16-31	18	72	2.0	65	35	57	18	.9	7	93

Apr.	1-15	38	89	1.5	100	0	18	28	1.6	-	-
	16-30	30	87	1.5	100	0	0	-	-	-	-
May	1-15	115	90	1.6	100	0	0	-	-	-	-
	16-28	192	89	1.5	100	0	0	-	-	-	-

[1]Determined by the presence of white spermatophores.
[2]Determined by the presence of red-dyed spermatophores.

Table 14.--Released sterile male (S) to St. Croix (N) male moth ratios in traps, released sterile female to St. Croix female ratios in blacklight traps, and number of expected and observed[1] St. Croix females mating with released sterile or St. Croix males in 1981

Sampling period	Gossyplure trap ratio[2] S♂:N♂	No. mated females collected: St. Croix	No. mated females collected: Sterile	Number St. Croix females mating with-- Sterile males: Exp.	Sterile males: Obs.	St. Croix males: Exp.	St. Croix males: Obs.	Black-light trap ratios[3] S♂:N♂	Number St. Croix females mating with-- Sterile males: Exp.	Sterile males: Obs.	St Croix males: Exp.	St Croix males: Obs.
Jan. 1-15	0.1	13	0	1	0	11	13	-	-	0	-	13
16-31	.1	25	0	2	0	21	25	-	-	0	-	25
Feb. 1-15	3.1	17	0	3	0	1	17	0.1	1	0	14	17
16-28	2.0	6	3	2	0	1	6	1.3	2	0	2	6
Mar. 1-15	1.0	31	10	10	0	10	31	.5	9	0	19	31
16-31	.7	16	109	31	0	44	16	20.7	6	0	<1	16
Apr. 1-15	.7	18	47	16	0	23	18	10.4	5	0	1	18
16-30	1.8	8	1	2	2	1	6	1.7	2	2	1	6
May 1-15	20.9	11	21	2	2	<1	9	13.7	3	2	1	9
16-31	94.2	9	88	1	0	<1	9	16.0	6	0	<1	9
June 1-15	43.9	2	12	<1	0	<1	2	33.8	<1	0	<1	2
16-30	97.9	2	5	<1	1	<1	1	28.2	<1	1	<1	1
July 1-15	38.3	10	13	<1	5	<1	5	32.3	1	5	<1	5
16-31	112.4	12	40	<1	4	<1	8	21.8	2	4	<1	8
Aug. 1-15	94.0	2	48	<1	0	<1	2	41.4	1	0	<1	2
16-31	75.8	11	88	1	5	<1	6	31.8	3	5	<1	6
Sept. 1-15	10.2	114	125	19	38	<1	76	8.2	24	38	2	76
16-30	25.7	117	254	15	39	<1	78	14.3	26	39	2	78
Oct. 1-15	29.3	95	108	6	18	<1	77	6.4	24	18	4	77
Total		519	972	[4]45	114	[4]1	405	283.1	[4]90	114	[4]6	405
Mean	34.3	27	51	[4]2	6	[4]<1	21	16.6	[4]5	6	[4]<1	21

[1]Determined by the presence of red spermatophores from released sterile males and white spermatophores from St. Croix males.
[2]Assumes ratios of released sterile females to St. Croix females were the same as male ratios in gossyplure-baited traps.
[3]Since blacklight traps catch more males than females, sterile female to native female ratios in the field were assumed to be the same as male ratios.
[4]Calculated using mean gossyplure or blacklight sterile male to St. Croix male trap ratios for the entire sampling period and assuming female ratios were the same.

for blacklight trap ratios. Observed mean numbers of sterile males, as measured by the presence of red-dyed spermatophores from released sterile males (for the total sampling period), mating with St. Croix females collected in blacklight traps, ranged from 0 to 39 and were significantly greater than expected based on gossyplure-baited male trap ratios ($\chi^2>100$, $P<0.01$), but not different than expected based on blacklight trap sterile male ratios ($\chi^2=0.2$, $P<0.50-0.70$). St. Croix male to female mating was significantly greater than expected ($\chi^2>400$, $P<0.01$).

From October 16, 1981, to March 31, 1982, red and white spermatophores were identified and recorded from dissections of both released sterile and St. Croix females caught in blacklight traps (table 15). The observed average numbers, for the entire sampling period, of matings of released sterile males to St. Croix females ($\chi^2=0.4$, $P=0.50-0.70$), of released sterile males to released sterile females ($\chi^2=3.2$, $P=0.05-0.10$), and of St. Croix male to released sterile females ($\chi^2=2.1$, $P=0.10-20$) were not different than expected on the basis of blacklight trap sterile male to St. Croix male ratios. St. Croix male to St. Croix female matings were greater than expected ($\chi^2>100$, $P<0.01$). Using gossyplure-baited trap sterile male to St. Croix male ratios, observed matings of released sterile males to St. Croix females ($\chi^2=7.1$, $P<0.01$) and of St. Croix males to released sterile females ($\chi^2=14.9$, $P<0.01$) were greater than expected. Released sterile male to released sterile female matings ($\chi^2=5.6$, $P=0.01-102$) were less than expected, and St. Croix male to St. Croix female matings ($\chi^2>100$, $P<0.01$) were significantly greater than expected.

Mating-Table Studies

There were no significant differences between the mating percentages of irradiated or untreated mass-reared females and St. Croix clipped-wing females on mating tables (table 16). Percentages of females mating during all sampling periods ranged from 26 to 74 percent. During preliminary releases of sterile moths (September 8 to 19, 1980), an average of 8 percent of all matings were with St. Croix males. During 10 nights of observation from January 8 to April 8, an average of 64 percent of all clipped-wing females on mating tables mated with St. Croix males. The percentages decreased to 25 and 4 percent during the June 3 to July 10 and December 5 to 10 sampling periods, respectively, and 40 percent during March 3 to 19, 1982.

Similar results were obtained when mixtures of mass-reared, irradiated, untreated, and St. Croix virgin females were placed on the same mating table in competitive situations (table 17). More mass-reared females on the mating tables

Table 15.--Released sterile male (S) to St. Croix (N) male ratios in gossyplure-baited and blacklight traps and numbers of expected[1] and observed[2] released sterile and St. Croix females mating with released sterile or St. Croix males

Sampling period	Ratios S♂:N♂	Mated females collected			Mating pair combinations								χ^2	P
		St. Croix	Sterile	Total	S♂ N♀ Exp.	S♂ N♀ Obs.	S♂ S♀ Exp.	S♂ S♀ Obs.	N♂ S♀ Exp.	N♂ S♀ Obs.	N♂ N♀ Exp.	N♂ N♀ Obs.		
Using gossyplure trap male catch ratios														
Oct. 16-31	74	44	73	117	1	15	115	50	1	23	<1	29	>100	<0.01
Nov. 1-15	70	74	349	423	4	37	415	307	4	42	<1	37	>100	<.01
16-30	38	28	190	218	4	16	209	163	4	27	<1	12	>100	<.01
Dec. 1-15	52	22	83	105	2	6	101	75	2	8	<1	16	>100	<.01
16-31	31	4	27	31	1	1	29	27	1	0	<1	3	5	.10-.20
1982														
Jan. 1-15	4	5	62	67	10	1	44	60	10	2	3	4	21	<.01
16-31	11	10	21	31	3	2	26	20	3	1	<1	8	52	<.01
Feb. 1-15	20	7	14	21	1	0	19	13	1	1	<1	7	39	<.01
16-28	9	3	79	82	7	1	67	75	7	4	1	2	8	.02-.05
Mar. 1-15	10	6	22	28	2	3	23	22	2	0	<1	3	7	.05-.10
16-31	12	13	10	24	2	4	20	9	2	1	<1	9	73	<.01
Total		216	930	1,147	[3]34	86	[3]1,078	821	[3]34	109	1	130	-	-
Mean	30	20	85	104	[3]3	8	[3]98	75	[3]3	10	<1[3]	12	>100	<.01
Using blacklight trap male catch ratios														
1981														
Oct. 16-31	15	44	73	117	7	15	103	50	7	23	<1	29	>100	<.01
Nov. 1-15	18	74	349	423	25	37	372	307	25	42	4	37	>100	<.01
16-30	13	28	190	218	15	16	190	163	15	27	1	12	>100	<.01
Dec. 1-15	23	22	83	105	4	6	97	75	4	8	<1	16	>100	<.01
16-31	11	4	27	31	3	1	26	27	3	0	<1		8	.02-.05
1982														
Jan. 1-15	46	5	62	67	1	1	64	60	1	2	<1	4	10	.01-.02
16-31	5	10	21	31	4	2	22	20	4	1	1	8	52	<.01
Feb. 1-15	17	7	14	21	1	0	19	13	1	1	<1	7	39	<.01
16-28	14	3	79	82	6	1	71	75	6	4	<1	2	6	.10-.20

Mar. 1-15	5	6	22	28	4	3	20	22	4	0	1	3	8	.02-.05
16-31	9	13	10	24	2	4	19	9	2	1	<1	9	72	<.01
Total	-	216	930	1,147	[3]69	86	[3]1,009	821	[3]69	109	[3]5	130	-	-
Mean	16	20	85	104	[3]6	8	[3]92	75	[3]6	10	[3]<1	12	>100	<.01

[1]Assumes ratios of released sterile females to St. Croix females were the same as male ratios in gossyplure-baited traps. Also, since blacklight traps consistently caught more males than females, sterile female to St. Croix female moth ratios were considered to be the same as male moth ratios in the blacklight traps.
[2]Determined by the presence of red spermatophores from released sterile males and white spermatophores from St. Croix males.
[3]Calculated using mean gossyplure or blacklight trap and sterile male to St. Croix male ratio for the entire sampling period and assuming the sterile female to St. Croix female ratio was the same.

Table 16.--Total[1] numbers of clipped-wing, virgin females recovered from individual mating tables and mating data during releases of sterile moths

Sampling period and moth strain	Number of females from mating tables	Percent mated[2]	Percent mated with-- St. Croix[3] males	Released[4] sterile males
1980				
Sept. 8-24 (8 nights):				
Mass-reared:				
Untreated..................	960	57a	87a	13a
Irradiated (20 krad).......	310	46a	92a	8a
St. Croix.....................	51	73a	85a	15a
1981				
Jan. 8-Apr. 8 (10 nights):				
Mass-reared, irradiated (20 krad).........	155	39a	56a	44a
St. Croix.....................	177	26a	71a	29a
June 3-July 10 (10 nights):				
Mass-reared, irradiated (20 krad)...................	911	66	25	75
Dec. 5-10 (3 nights):				
St. Croix	94	41	4	96
1982				
Mar. 3-19 (7 nights):				
Mass-reared, untreated.........	392	74	40	60
Apr. 7-21 (6 nights):				
Mass-reared, irradiated) (20 krad)...................	464	42	100	0

[1]20-30 virgin females on each of 2 to 4 mating tables per night.
[2]Means within each sampling date in the same column not followed by the same letter are significantly different by Duncan's (1955) multiple-range test ($P=0.05$).
[3]Determined by presence of white spermatophores plus the identification of the male moth.
[4]Determined by presence of red spermatophoes plus the identification of the male moth.

Table 17.--Mean[1] percentages of clipped-wing, virgin females mated and percentages mated with St. Croix or released sterile males when placed on the same mating tables in cotton plots during releases of sterile moths

Sampling period and moth strain	Number of females from mating tables	Percent mated	Percent mated with-- St. Croix[2] males	Released[3] males
1980				
Sept. 8-24 (4 nights):				
Mass-reared:				
Untreated..................	28	65a	95a	5a
Irradiated (20 krad).......	35	83a	90a	10a
St. Croix......................	46	80a	82a	18a
1981				
Jan. 15-Apr. 15 (9 nights):				
Mass-reared, irradiated (20 krad).........	116	25a	42a	58a
St. Croix......................	129	34a	43a	57a
Dec. 7-11:				
Mass-reared, irradiated (20 krad)....................	53	35a	0a	100a
St. Croix	54	42a	0a	100a
1982				
Mar. 24-25:				
Mass-reared:				
Untreated..................	124	77a	9a	91a
Irradiated (20 krad).......	130	73a	2	98a

[1]Means of 10-15 virgin females moths of each strain placed on each of 1-2 mating tables each night. Means during the same sampling period in the same column followed by the same letter are not significantly different by Duncan's (1955) multiple-range test (*P*=0.05).
[2]Determined by presence of white spermatophores plus the identification of the male moth.
[3]Determined by presence of red spermatophoes plus the identification of the male moth.

on most sampling nights and mated about 1 hour earlier than St. Croix females (tables 18 and 19), although the peaks of activity were similar.

Table 18.--Mean[1] numbers of mating moth pairs collected from individual mating tables in cotton plots during releases of sterile moths

Sampling period and moth strain	Hourly periods (12 p.m. to 6 a.m.) 12-1	1-2	2-3	3-4	4-5	5-6
1980						
Sept. 8-24 (8 nights):						
Mass-reared, untreated:						
Mean number mating pairs	0.0	1.8	14.0	1.3	0.0	0.0
Percent of total	.0	10.5	81.0	7.8	.7	.0
Mass-reared, irradiated (20 krad):						
Mean number mating pairs	.0	1.0	4.3	.5	.4	.0
Percent of total	.0	10.0	74.4	7.0	9.0	.0
St. Croix:						
Mean number mating pairs	.0	2.5	11.0	2.5	1.0	.0
Percent of total	.0	13.0	67.0	15.0	6.0	.0
1981						
Jan. 8-Apr. 8 (10 nights):						
Mass-reared, irradiated (20 krad):						
Mean number mating pairs	2.8	4.3	3.8	.0	.0	.0
Percent of total	18.8	25.6	55.5	.0	.0	.0
St. Croix:						
Mean number mating pairs	.0	.8	3.7	.8	.0	.0
Percent of total	.0	9.5	63.5	27.0	.0	.0
June 3-July 10 (10 nights):						
Mass-reared, irradiated (20 krad):						
Mean number mating pairs	<.1	1.1	6.8	5.7	.7	.2
Percent of total	.2	6.6	41.2	43.1	5.4	3.5
Dec. 5-10 (3 nights), St. Croix:						
Mean number mating pairs	.0	.0	1.0	2.8	.0	.8
Percent of total	.0	.0	34.0	34.5	.0	31.5
1982						
Mar. 3-19 (7 nights):						
Mass-reared, untreated:						
Mean number mating pairs	1.2	6.2	11.4	1.1	.0	.0
Percent of total	7.5	32.4	55.1	6.0	.0	.0

[1]Means of number collected on 2 to 4 mating tables per night.

Table 19.--Mean[1] numbers of mating moth pairs collected on the same mating table in cotton plots during releases of sterile moths

Sampling period and moth strain	Hourly periods (12 p.m. to 6 a.m.)					
	12-1	1-2	2-3	3-4	4-5	5-6
1980						
Sept. 8-24 (4 nights):						
Mass-reared, untreated:						
Mean number mating pairs............	0.0	1.0	3.7	0.3	0.0	0.0
Percent of total....................	0	20.0	74.0	6.0	0	0
Mass-reared, irradiated (20 krad):						
Mean number mating pairs............	0	1.7	3.3	.3	0	0
Percent of total....................	0	32.0	62.0	6.0	0	0
St. Croix:						
Mean number mating pairs............	0	1.0	.7	3.0	0	0
Percent of total....................	0	21.0	15.0	64.0	0	0
1981						
Jan. 15-Apr. 15 (9 nights):						
Mass-reared, irradiated (20 krad):						
Mean number mating pairs............	0	.3	3.0	.5	.1	0
Percent of total....................	0	8.0	77.0	13.0	2.0	0
St. Croix:						
Mean number mating pairs............	0	0	1.1	1.4	.2	0
Percent of total....................	0	0	41.0	52.0	7.0	0
Dec. 7-11 (4 nights):						
Mass-reared, irradiated (20 krad):						
Mean number mating pairs............	0	.3	0	1.8	0	0
Percent of total....................	0	14.0	0	86.0	0	0
St. Croix:						
Mean number mating pairs............	0	0	1.3	1.3	0	0
Percent of total....................	0	0	50.0	50.0	0	0
1982						
Mar. 24-25 (2 nights):						
Mass-reared, untreated:						
Mean number mating pairs............	0	.9	7.4	2.1	.6	.9
Percent of total....................	0	15.0	57.0	16.0	5.0	7.0
Mass-reared, irradiated (20 krad):						
Mean number mating pairs............	0	3.7	7.3	1.0	.4	.9
Percent of total....................	0	28.0	55.0	7.0	3.0	7.0

[1]Means of number collected from 1 to 2 mating tables during each night of each sampling period.

Collections of Moths in Release Plots

During the September 8 to 24, 1980, sampling period, 152 St. Croix and 10 released sterile males and 137 St. Croix and seven released sterile females were hand-collected in the release plots (table 20). Numbers of sterile males collected ranged from 124 to 1,123 and females from 132 to 574 during sampling periods from January 15, 1981, to March 25, 1982, after large-scale releases of sterile moths were begun. All combinations of mating pairs were collected. The highest percentage (89 percent) of mating pairs collected was for released sterile males mating with released sterile females.

The expected and observed numbers of mating pair combinations are shown in table 21. The expected numbers were calculated using the ratios of the total numbers of hand-collected, released sterile and St. Croix insects. The hand-collected numbers of mating pairs of released sterile males and St. Croix females and of released sterile females and St. Croix males were less than expected. Collected numbers of mating pairs of released sterile males and females and of St. Croix males and females were greater than expected.

Table 20.--Total[1] numbers of St. Croix (N) and released sterile (S) moths hand-collected and numbers collected as mating pairs in cotton plots during releases of sterile moths

Sampling period	Total collected				Total collected as mating pairs			
	Males		Females					
	N	S	N	S	N♂ X S♀	N♂ X N♀	S♂ X N♀	S♂ X S♀
1980								
Sept. 8-24 (8 nights)	152	10	137	7	0	2	0	1
1981								
Jan. 15-April 15 (10 nights)	35	124	34	132	3	2	1	52
June 3-July 10 (10 nights)	63	1,123	86	574	5	6	8	239
Dec. 9-11 (3 nights)	8	293	5	272	3	0	2	143
1982								
Mar. 3-25 (6 nights)	117	336	94	155	13	11	1	29

[1]Plots searched for 4.5 to 6.0 hours by 1 to 2 people on each night of each sampling period.

Table 21.--Expected and observed combinations of mating pairs hand-collected in cotton plots during releases of sterile moths based on ratios of total number of St. Croix (N) and released sterile (S) moths captured

Mating combination					
Male	Female	Expected	Observed	χ^2	P
1981					
S	N	47.0	11.0	27.6	<0.01
S	S	385.0	434.0	6.2	.01-.02
N	S	28.0	11.0	10.3	<.01
N	N	4.0	8.0	4.0	.02-.05
Total.........		-	-	48.1	<0.01
1982					
S	N	16.0	1.0	14.0	<0.01
S	S	24.0	29.0	1.0	.30-.50
N	S	9.0	13.0	1.7	.10-.20
N	N	5.0	11.0	7.2	<.01
Total.........		-	-	23.9	<0.01
Combined 1981 + 1982					
S	N	73.0	12.0	50.9	<0.01
S	S	388.0	463.0	14.5	<.01
N	S	47.0	24.0	11.3	<.01
N	N	10.0	19.0	8.1	<.01
Total.........		-	-	[1]84.8	<0.01

[1]Total χ^2 value.

The results of the dissections of hand-collected released sterile and St. Croix females to identify red and white spermatophores are shown in table 22. The total numbers (December 9 to March 25) of expected and observed sterile and St. Croix moth matings, based on identification of the spermatophores, agree well with the mating pair collections, except for the released sterile male to released sterile female category. The hand collection of mating pairs indicated that significantly greater numbers of sterile to sterile matings were occurring, whereas the data from the dissections of females indicated that significantly fewer sterile to sterile moth matings were occurring than expected.

Table 22.--Expected[1] and observed numbers of sterile (S) and St. Croix (N) moth mating interactions based on identification[2] of spermatophores in dissected female moths

Mating combination: Male	Mating combination: Female	Expected	Observed	χ^2	P
1981					
Jan. 15-July 10					
S	N	43.0	90.0	51.3	<0.01
S	S	244.0	-	-	-
N	S	19.0	-	-	-
N	N	3.0	220.0	214.0	<.01
Total.........		-	-	265.4	<0.01
Dec. 9-11					
S	N	7.0	5.0	0.6	.30-.50
S	S	332.0	315.0	.9	.30-.50
N	S	11.0	27.0	23.2	<.01
N	N	<1.0	2.0	16.2	<.01
Total.........		-	-	40.9	<0.01
1982					
Mar. 3-25					
S	N	78.0	56.0	6.2	.01-.02
S	S	136.0	54.0	49.4	<.01
N	S	46.0	36.0	2.2	.10-.20
N	N	29.0	143.0	448.1	<.01
Total.........		-	-	505.9	<0.01
Dec. 9-Mar. 25					
S	N	102.0	61.0	16.5	<0.01
S	S	428.0	369.0	8.1	<.01
N	S	89.0	63.0	7.6	<.01
N	N	19.0	145.0	835.6	<.01
Total.........		-	-	867.8	<0.01

[1]Based on ratios of all hand-collected released sterile and St. Croix insects during the sampling periods.
[2]Red spermatophores from released sterile males, white spermatophores from St. Croix males.

The total numbers and percentages of released sterile and St. Croix male and female hand-collected mating pair combinations, collected hourly from midnight to 6 a.m., are shown in table 23. The highest percentages of mating pairs of St. Croix males to released sterile females were hand-collected between

3 and 4 a.m. Mating pairs of released sterile males to St. Croix females and of released sterile males to released sterile females were hand-collected most often between the hours of 2 and 4 a.m. St. Croix mating moth pairs were collected first between the hours of 12 p.m. and 2 a.m. with peak numbers caught between 2 p.m. and 4 p.m.

During the September 8 to 24, 1981, sampling period, 80 percent (2.2 spermatophores per female) of the hand-collected St. Croix females and 43 percent (1.7 spermatophores per female) of the sterile females were mated (table 24). Most (99 percent) of the St. Croix females had mated with St. Croix males. St. Croix and sterile female mating during the large-scale releases of sterile moths (January 1981 to March 1982) ranged from 84 to 100 percent (1.4 to 3.7 spermatophores per female) and 43 to 93 percent (1.1 to 2.6 spermatophores per female), respectively. The highest percentages (85 percent, red spermatophores) of collected St. Croix female to released sterile male matings occurred during the December 9 to 11, 1981, sampling period when ratios of sterile to St. Croix males averaged about 50 to 1.

Table 23.--Numbers of released sterile (S) and St. Croix (N) mating combinations collected at hourly intervals from 12 p.m. to 6 a.m. in sterile moth release cotton plots, 1981-1982

Mating combination		Hourly intervals						
Male	Female	12-1	1-2	2-3	3-4	4-5	5-6	Total
N	S							
No. of mating pairs....		1	2	3	17	1	0	24
Percent of total.......		4	8	13	71	4	0	100
N	N							
No. of mating pairs....		0	3	5	5	6	0	19
Percent of total.......		0	16	26	26	32	0	100
S	N							
No. of mating pairs....		0	0	5	5	2	0	12
Percent of total.......		0	0	42	42	16	0	100
S	S							
No. of mating pairs....		[1]13	68	148	205	23	6	463
Percent of total.......		3	15	32	44	5	1	100

[1]Includes 3 mating pairs collected between 9 p.m. and midnight.

Table 24.--St. Croix and released sterile females hand collected[1] in cotton plots during releases of sterile moths and mating data

Sampling period and moth strain	Number of female moths collected	Percent mated	Spermatophores per mated female	Percent mating with-- St. Croix male moths	Percent mating with-- released sterile male moths
1980					
Sept. 8-24 (8 nights):					
St. Croix females.......	137	80	2.2	99	1
Sterile females.........	7	43	1.7	-	([2])
1981					
Jan. 15-Apr. 15 (10 nights):					
St. Croix females.......	34	88	1.5	98	2
Sterile females.........	132	61	1.4	-	([2])
June 3-July 10 (10 nights):					
St. Croix females.......	86	84	3.7	66	34
Sterile females.........	574	63	1.5	-	([2])
Dec. 9-11 (3 nights):					
St. Croix females.......	5	100	1.4	28	72
Sterile females.........	272	93	2.6	8	92
1982					
Mar. 3-25 (6 nights):					
St. Croix females.......	94	88	2.4	72	28
Sterile females.........	155	52	1.1	40	60

[1]Plots searched for 4.5 to 6.0 hours by 1 to 2 people on each night of each sampling period.
[2]Red and white spermatophores not recorded.

Hourly Catches of Released Sterile Males in Gossyplure-Baited Traps

Generally, more released sterile males than St. Croix males were collected in gossyplure-baited traps, although the numbers were not always significantly different (table 25). Also, released sterile males were caught in traps earlier (12 p.m.-3 a.m.) than St. Croix males.

Infestations in Cotton Flowers and Bolls

Mean percentages of flowers infested with pink bollworm larvae in cultivated cotton on the Kingshill and Virgin Islands Experiment Stations in 1980, before sterile moth releases, were 10 to 17 percent in January, decreasing in February and March, with peak infestations occurring in April and May and August through December (table 26, fig. 10). Generally, infestations in cotton flowers were higher in the cultivated plots on the Kingshill and Virgin Islands Experiment Stations than in the flowers in cultivated plots off the station or in flowers of Sea Island cotton.

Table 25.--Mean[1] number of St. Croix and released sterile males caught in gossyplure-baited traps during hourly sampling periods from 6 p.m. to 6 a.m. during releases of sterile moths in cotton plots

Sampling period and time of collection	Number of trap nights	Male moths: St. Croix	Percent of total collected	Released sterile	Percent of total collected
1981					
Feb. 25-Apr. 15:					
6-12 p.m.	16	0.0a	0	7.5a	34
12-1 a.m.	32	.0a	0	4.6a	21
1-2	32	.2a	13	2.5a	12
2-3	32	.9a	55	2.7a	12
3-4	32	.2a	13	.7a	3
4-5	32	.1a	6	2.5a	12
5-6	32	.2a	13	1.4a	6
Total	208	1.6	-	21.9	-
June 10-July 10:					
6-12 p.m.	53	0.0d	0	0.8d	2
12-1 a.m.	54	.0d	0	1.4cd	4
1-2	55	.1d	14	8.4b	23
2-3	56	.4d	58	19.8a	54
3-4	56	.1d	14	4.6c	13
4-5	55	<.1d	14	1.0d	3
5-6	49	.0d	0	.6d	1
Total	378	0.7	-	36.6	-
Dec. 8-10:					
6-12 p.m.	36	0.0b	0	26.3a	35
12-1 a.m.	36	.0b	0	4.3b	6
1-2	36	.4b	57	29.6a	39
2-3	36	.3b	43	9.7b	13
3-4	36	.0b	0	3.1b	4
4-5	36	.0b	0	.8b	1
5-6	36	.0b	0	1.1b	2
Total	252	0.7	-	74.9	-
1982					
Mar. 3-31:					
6-12 p.m.	20	0.0b	0	3.6ab	14
12-1 a.m.	32	.0b	0	3.7ab	15
1-2	32	.8b	33	4.9ab	19
2-3	32	1.1b	46	8.0a	32
3-4	32	.5b	21	2.9b	12
4-5	32	.0b	0	1.0b	4
5-6	32	.0b	0	1.1b	4
Total	212	2.4	-	25.2	-

Table 25.--Mean[1] number of St. Croix and released sterile males caught in gossyplure-baited traps during hourly sampling periods from 6 p.m. to 6 a.m. during releases of sterile moths in cotton plots--Continued

Sampling period and time of collection	Number of trap nights	Male moths: St. Croix	Percent of total collected	Released sterile	Percent of total collected
Apr. 1-7:					
6-12 p.m.	12	0.7b	36	5.3a	98
12-1 a.m.	12	.3b	16	.1b	2
1-2	12	.3b	16	.0b	0
2-3	12	.2b	11	.0b	0
3-4	12	.4b	21	.0b	0
4-5	12	.0b	0	.0b	0
5-6	12	.0b	0	.0b	0
Total	84	1.9	-	5.4	-

[1]Means of 2 to 6 traps per sampling period during 16 to 56 trap nights. Means during the same sampling period not followed by the same letter are significantly different by Duncan's (1955) multiple-range test (*P*=0.05).

Table 26.--Mean[1] percentages of cotton flowers infested by pink bollworms in all plots in 1980 before release of sterile moths

Sampling period		Cultivated cotton		
		Release plots	Control plots	Sea Island cotton
Jan.	1-15	16.8a	0b	-
	16-31	9.8a	0b	-
Feb.	1-15	7.0a	2.0b	-
	16-28	6.5a	.8b	-
Mar.	1-15	7.5a	.3b	-
	16-31	7.2a	0b	-
Apr.	1-15	15.3a	2.2a	-
	16-30	18.7a	7.6b	-
May	1-15	29.1a	0b	-
	16-31	25.8	-	-
June	1-15	13.3	-	-
	16-30	6.4	-	-
July	1-15	5.5	-	-
	16-31	8.0	-	-
Aug.	1-15	52.3a	3.5b	-
	16-31	47.3a	2.6b	-
Sept.	1-15	58.8a	4.9b	-
	16-30	42.6a	0b	-
Oct.	1-15	23.6a	0b	50.0a
	16-31	66.4a	0c	33.3b
Nov.	1-15	-	31.0a	5.7a
	16-30	-	-	-
Dec.	1-15	25.7a	15.6a	2.3b
	16-31	58.0a	17.0b	25.6b

[1]Means of 2 to 20 observations. Means within rows followed by the same letter are not significantly different by Duncan's (1955) multiple-range test (P=0.05).

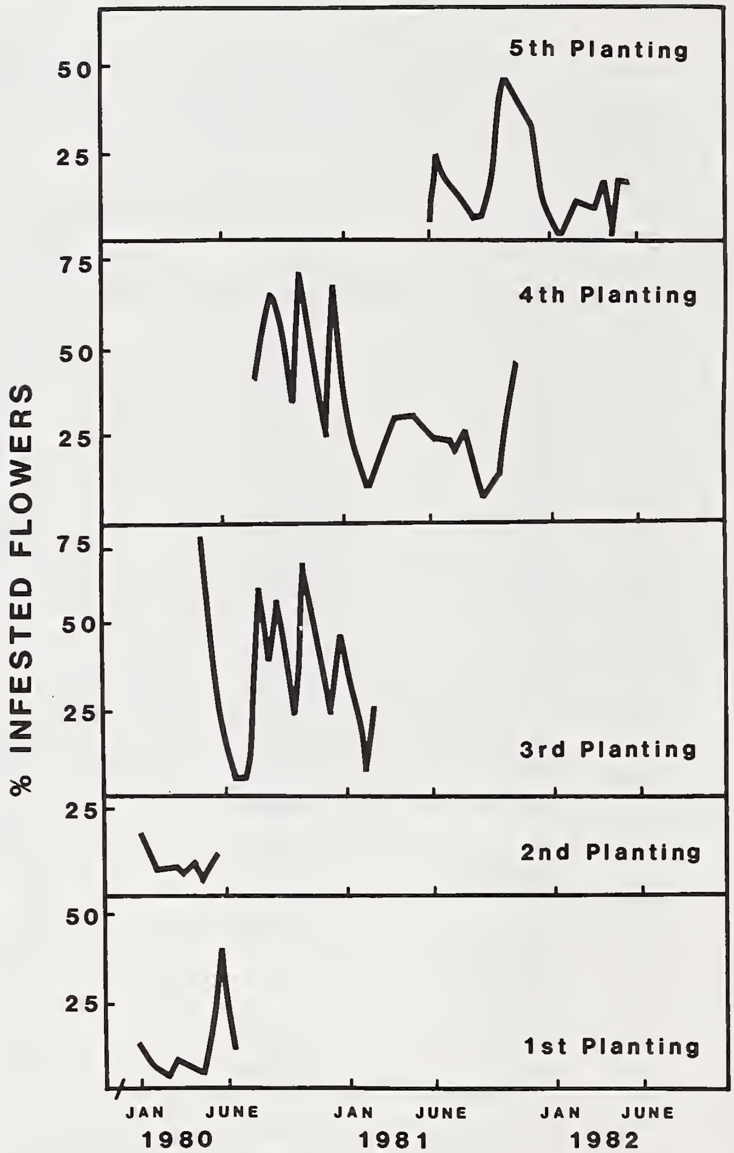

Figure 10. Mean percentages of cotton flowers infested by pink bollworms in each of five cultivated cotton plantings on the Kingshill and Virgin Islands Experiment Stations before (1980) and after (1981, 1982) the start of large-scale releases of sterile moths on December 29, 1980.

Flower infestations in release plots in January 1981 averaged 31 percent, decreased in February and increased thereafter through mid-August (table 27, fig. 10). Percentages of infested flowers decreased during late August through mid-September and increased during late September to mid-December. Percentage of infested flowers December 16 to 31 was 10 percent, decreased in January 1982, was 4 and 11 percent in February and March 1982, and increased to 17% after the end of sterile moth releases in May (table 28, fig. 10).

Percentages of infested flowers in cultivated cotton plots off the station ranged from 3 to 49 percent from January 1 through March 1 to 15, 1981, and 17 to 34 percent from late April to

Table 27.--Mean[1] percentages of cotton flowers infested by pink bollworms in all plots in 1981

1981		Cultivated cotton: Release plots	Cultivated cotton: Control plots	Sea Island cotton plots
Jan.	1-15	35.6a	37.0a	12.5a
	16-31	26.0a	17.2a	16.7a
Feb.	1-15	12.9a	3.0b	16.1a
	16-28	16.1b	46.0a	30.7a
Mar.	1-15	17.2c	48.5a	28.9b
	16-31	23.6a	17.0a	26.7a
Apr.	1-15	30.3a	-	12.1a
	16-30	-	10.0	-
May	1-15	30.7a	34.0a	55.7a
	16-31	-	-	-
June	1-15	18.9a	17.4a	-
	16-30	24.9	-	-
July	1-15	18.6	-	-
	16-31	16.0	-	-
Aug.	1-15	14.6	-	-
	16-31	8.7	-	-
Sept.	1-15	9.7	-	-
	16-30	13.9	-	-
Oct.	1-15	36.1	-	-
	16-31	43.3	-	-
Nov.	1-15	40.4a	0b	0b
	16-30	-	0a	0a
Dec.	1-15	32.5a	16.2a	4.1a
	16-31	10.0a	4.7a	12.5a

[1]Means of 2 to 35 observations. Means within rows followed by the same letter are not significantly different by Duncan's (1955) multiple-range test ($P=0.05$).

early June (table 27, fig. 11). Plots dried out in late June due to drought. In replanted plots, no flowers were infested with pink bollworms until December 1981 when about 10 percent of the flowers contained pink bollworm larvae. Percentages of infested flowers increased to 8 percent during January 1 to 15, 1982, and reached 27 percent during April 1 to 15 (table 28, fig. 11).

Table 28.--Mean[1] percentages of cotton flowers infested by pink bollworms in all plots in 1982

1982		Cultivated cotton: Release plots	Cultivated cotton: Control plots	Sea Island cotton plots
Jan.	1-15	5.4a	7.8a	0b
	16-31	2.1a	12.3a	6.7a
Feb.	1-15	4.4a	9.6a	10.7a
	16-28	10.9a	18.8a	25.0a
Mar.	1-15	9.7a	19.5a	0a
	16-31	9.9a	11.8a	4.6a
Apr.	1-15	17.0a	27.1a	0b
	16-30	2.5a	-	0a
May	1-15	17.4	-	-
	16-31	17.3a	28.0a	-

[1]Means of 20 to 35 observations. Means within rows not followed by the same letter are significantly different by Duncan's (1955) multiple-range test (*P*=0.05)

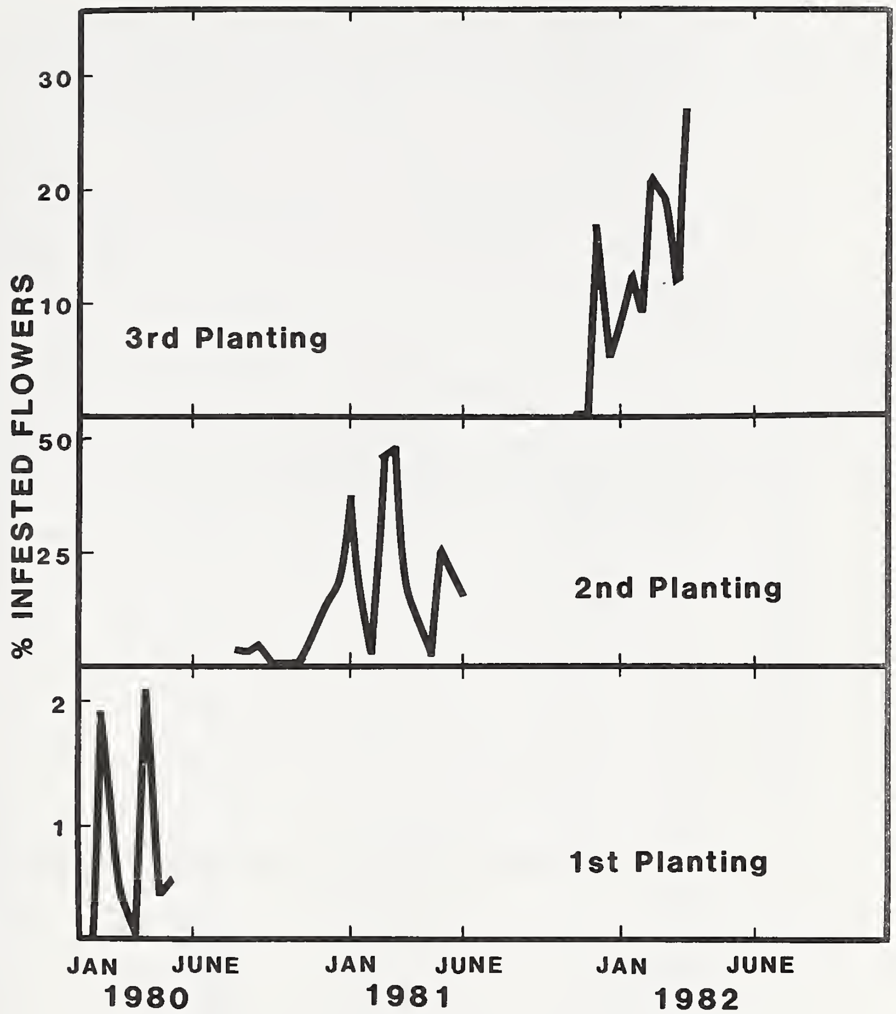

Figure 11.--Mean percentages of cotton flowers infested by pink bollworm in each of three sequentially cultivated cotton plantings (controls) before (1980) and after (1981, 1982) the start of large-scale releases of sterile moths (plots 1.6 to 18 km from the areas of sterile moth releases) off the Kingshill and Virgin Islands Experiment Stations.

Percentages of infested cotton flowers in Sea Island cotton averaged 15 percent in January 1981, increasing to a peak percentage of 31 percent from February 16 to 28, decreasing to 12 percent from April 1 to 15, and increasing to 56 percent from May 1 to 15 (table 27, fig. 12). Flowering of Sea Island cotton began again in late October 1981. An average of 8 percent of the flowers contained pink bollworm larvae in December 1981 (table 27, fig. 12), decreasing to 7 percent from January 16 to 31, 1982, 25 percent in late February, and decreasing thereafter to 0 percent in April (table 28, fig. 12).

In 1980, boll infestations in cotton plots on Kingshill and Virgin Islands Experiment Stations ranged from 1.2 to 3.8 larvae per boll from January through July, peaked at 7.6 larvae per boll during the August 16 to 31 sampling period, and decreased thereafter to 1.4 larvae per boll in late

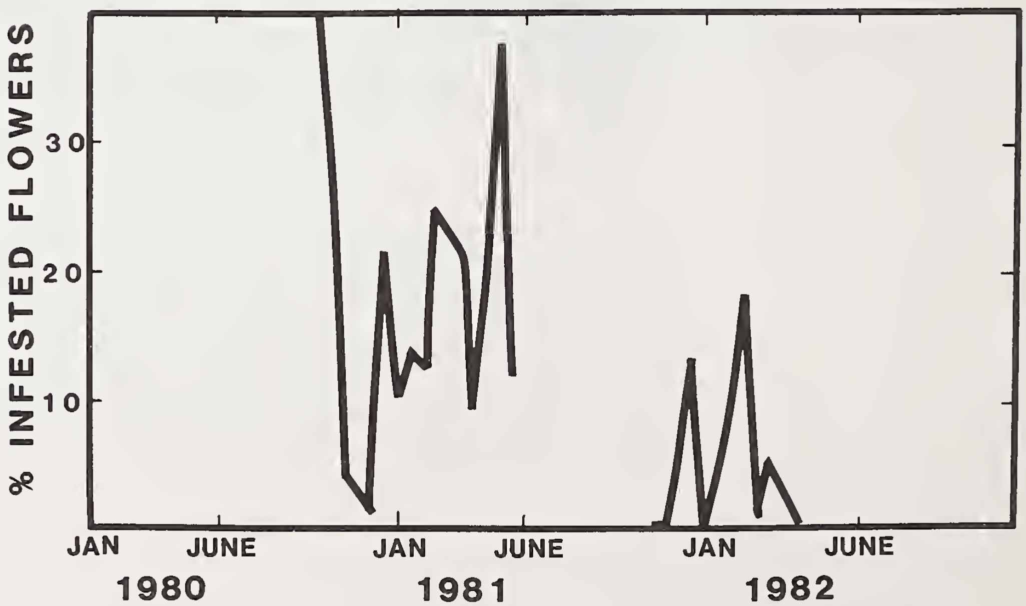

Figure 12.--Mean percentages of Sea Island cotton flowers infested by pink bollworm before (1980) and after (1981, 1982) the start of large-scale releases of sterile moths (plots 3 to 20 km from the areas of sterile moth releases).

December (table 29, fig. 13). Boll infestations in cultivated cotton plots off the station and in Sea Island cotton ranged from <.01 to 0.9 and <0.1 to 1.9, respectively, from January through December 1980.

Table 29.--Total number of cotton bolls sampled and mean[1] number of larvae per boll in all plots in 1980 before release of sterile moths

Sampling period		Cultivated cotton				Sea Island cotton plots	
		Sterile release plots		Control plots			
		No. bolls sampled	Larvae/ boll	No. bolls sampled	Larvae/ boll	No. bolls sampled	Larvae/ boll
Jan.	1-15	20	16.0a	151	0.2b	716	0.2b
	16-31	103	1.2a	224	.5b	250	.1b
Feb.	1-15	-	-	81	.1a	410	.2a
	16-28	90	1.7a	81	.4b	220	.2b
Mar.	1-15	53	2.1a	123	.2b	547	<.1b
	16-31	49	1.8a	60	.3b	162	.3b
Apr.	1-15	116	1.4a	186	.5b	624	.1b
	16-30	172	2.0a	174	.7b	286	.2b
May	1-15	120	2.2a	164	.7b	272	.1b
	16-31	92	1.1a	-	-	56	.2b
June	1-15	454	1.3a	450	.5b	-	-
	16-30	1,695	1.6	-	-	-	-
July	1-15	643	2.2	-	-	-	-
	16-31	1,240	3.8	-	-	-	-
Aug.	1-15	795	6.8	-	-	-	-
	16-31	150	7.6	-	-	-	-
Sept.	1-15	250	7.2a	100	<.1b	-	-
	16-30	450	5.0a	200	.3b	-	-
Oct.	1-15	1,050	4.7a	100	.9b	50	1.9b
	16-31	350	6.3	-	-	-	-
Nov.	1-15	250	2.8a	50	.1a	200	.8a
	16-30	-	-	-	-	300	.4
Dec.	1-15	979	1.7a	450	.2b	950	.2b
	16-31	700	1.4a	250	.7b	1,457	.4b

[1]Means of 2 to 31 observations per sampling period. Means within a row in the same sampling period not followed by the same letter are significantly different by Duncan's (1955) multiple-range test ($\underline{P}$=0.05).

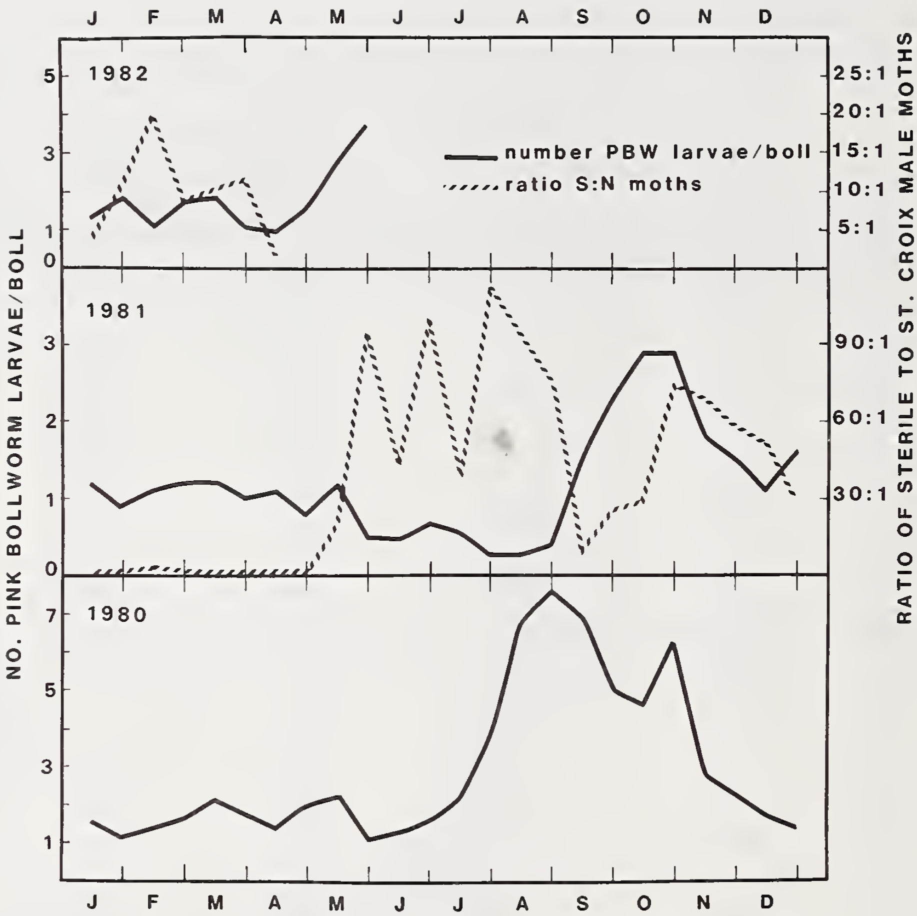

Figure 13.--Mean number of pink bollworm larvae per cotton boll in cultivated cotton on the Kingshill and Virgin Islands Experiment Stations in 1980 before releases of sterile moths (January 1, 1981, to March 31, 1982), during releases of sterile moths (April and May 1982), after the end of releases of sterile moths, and ratios of sterile (S) to St. Croix (N) males caught in gossyplure-baited traps.

Table 30.--Total number of cotton bolls sampled and mean[1] number of larvae per boll in all plots in 1981

Sampling period		Cultivated cotton: Sterile release plots: No. bolls sampled	Larvae/ boll	Control plots: No. bolls sampled	Larvae/ boll	Sea Island cotton: No. bolls sampled	Larvae/ boll
Jan.	1-15	600	1.2a	200	<0.1b	620	0.3b
	16-31	550	.9a	350	.8a	450	.1b
Feb.	1-15	500	1.1a	100	1.3a	750	.2b
	16-28	700	1.2a	150	.2b	1,000	.3b
Mar.	1-15	200	1.2a	100	.0b	150	.6b
	16-31	250	1.0a	-	<.1b	550	.4b
Apr.	1-15	50	1.1a	-	-	550	.4b
	16-30	200	.8a	-	-	-	-
May	1-15	50	1.2a	-	-	50	1.0a
	16-31	1,100	.5a	100	1.2a	50	1.5a
June	1-15	1,474	.5b	150	2.9b	-	-
	26-30	358	.7	-	-	-	-
July	1-15	815	.6	-	-	-	-
	16-31	1,150	.3	-	-	-	-
Aug.	1-15	1,104	.3	-	-	-	-
	16-31	1,148	.4	-	-	-	-
Sept.	1-15	1,500	1.5	-	-	-	-
	16-30	1,352	2.3	-	-	50	1.0
Oct.	1-15	1,300	2.9	-	-	-	-
	16-31	1,200	2.9	-	-	-	-
Nov.	1-15	1,100	1.8	-	-	-	-
	16-30	200	1.5a	-	-	300	.7b
Dec.	1-15	825	1.1a	140	.2b	1,469	.3b
	16-31	599	1.6a	-	-	350	.3b

[1]Means of 2 to 42 observations per sampling period. Means within a row in the same sampling period not followed by the same letter are significantly different by Duncan's (1955) multiple-range test (_P_=0.05).

In 1981, larval infestations were 1.2 larvae per boll when large-scale releases of sterile moths were begun in the Kingshill and Virgin Islands Experiment Station cotton plots (table 30, fig. 13). Infestations averaged 0.8 to 1.2 larvae per boll through May 1 to 15. Beginning May 16 to 31, this dropped to 0.5 larvae per boll, decreased to 0.3 to 0.4 larvae per boll in August, increased thereafter to 1.5 larvae per boll September 1 to 15, and ranged from 1.1 to 2.9 larvae per boll from the September 16 to 30 sampling period through the end of December 1981. Infestations ranged thereafter from 0.9

Table 31.--Total number of cotton bolls sampled and mean[1] number of larvae per boll in all plots in 1982

Sampling period		Cultivated cotton: Sterile release plots: No. bolls sampled	Larvae/boll	Control plots: No. bolls sampled	Larvae/boll	Sea Island cotton: No. bolls sampled	Larvae/boll
Jan.	1-15	1,000	1.3a	137	1.3a	1,541	0.2b
	16-31	950	1.8a	215	1.3a	1,200	.3b
Feb.	1-15	1,750	1.1a	200	.9a	350	.3b
	16-28	1,100	1.7a	100	.9b	500	.2b
Mar.	1-15	950	1.8a	250	.6b	550	.2b
	16-31	900	1.0	-	-	-	-
Apr.	1-15	1,750	.9b	250	1.7a	900	.1c
	16-30	1,500	1.5a	-	-	550	.4b
May	1-15	1,300	2.7	-	-	-	-
	16-28	1,400	3.7	-	-	-	-

[1]Means of 2 to 35 observations per sampling period. Means within a row in the same sampling period not followed by the same letter are significantly different by Duncan's (1955) multiple-range test ($\underline{P}$=0.05).

to 1.8 larvae per boll during January 1 to 15, 1982, to April 1 to 15, 1982, and increased after the last release of sterile moths to 3.7 larvae per boll (table 31, fig. 13).

Some (7 percent of 29, 10 percent of 42, 15 percent of 13, 0 percent of 7, 4 percent of 25, and 0 percent of 3 on October 7 and November 12, 1981; February 5 and 23, and May 6 and 10, 1982, respectively) field-collected, mature, male larvae from bolls in the sterile moth release plots had chromosomal aberrations indicating sexual interaction of the sterile release moths with St. Croix moths, since few progeny result from 20 krad sterile male-sterile female matings (Graham et al. 1972, Henneberry et al. 1980).

In cultivated cotton plots off the station, larval infestations were <0.1 larva per boll in early January 1981, increasing to 1.3 larvae per boll February 1 to 15, decreasing to <0.1 larva per boll March 1 to 15, and increasing to 1.2 to 2.9 larvae per boll in June when the cotton plants died due to drought. Plots were replanted from seed in October 1981, and infestations were 1.3 larvae per boll in January 1982, 0.6 to 0.9 larva per boll in February to March 15, and 1.7 larvae per boll April 1 to 15 (table 31).

Infestations in Sea Island cotton were low, ranging from 0.3 to 0.6 larva per boll from January 1 to April 15, 1981, and increasing to 1.0 to 1.5 larvae per boll May 1 to 15 to May 16 to 31 (table 30). There was 1.0 larva per boll in September 1981, 0.7 larva per boll November 16 to 30, and an average of 0.3 larva per boll through April 1982 (table 31).

DISCUSSION

High numbers (about 100,000 per release day per 1.5 ha) of released sterile pink bollworm moths were required to achieve suppression of high native infestations in bolls.

The efficiency and effectiveness of the sterile insect release method of insect population suppression are affected by many factors related to the techniques used in the system. Mass-rearing capability for producing large numbers of pink bollworm moths has improved greatly in recent years (Mangum et al. 1969). The effects of rearing conditions, handling, shipment, diet, and possible genetic selection during colonization (which may have resulted in changes in insect behavior) and other biological criteria (Boller 1972, Proshold and Bartell 1972) on the performance of released sterile moths, are unknown. The mass-reared, sterilized moths released during the present studies were from stocks reared in artificial culture for more than 10 years.

The reasons for the need for high ratios of released sterile to St. Croix moths to reduce cotton boll infestations may be partially explained by (1) inadequate nutritional quality or other factors associated with the artificial diet of the mass-reared, released insects; (2) adverse effects of handling in the mass-rearing and shipping procedures; (3) adverse impact of the irradiation treatment; and (4) genetic selection in mass-rearing of a trait(s) that physically, physiologically, or behaviorally prevents males from responding to native females (or the native females become nonreceptive as a result of altered physical, physiological or behavioral patterns of the released, mass-reared sterile males).

It is difficult to apportion the individual impact of each of these factors on the performance of the released, mass-reared, sterile moths. Probably, the combined effects of all these factors are reflected in overall reduced quality and vigor of the sterile insects under field conditions.

The effects of the various components of the artificial diet and other mass-rearing procedures on reproductive physiology, behavior, and other biological aspects of the mass-reared moths need to be determined. Research should be started to determine the feasibility of producing higher quality, more vigorous and competitive pink bollworm moths for use in sterile moth release programs.

The effect of the handling and shipping procedures on the overall vigor of the released, sterile insects in the present study is difficult to assess. Mortality of insects that were in transit 20 to 26 hours was low on arrival at St. Croix (7 percent), and, on the average, 45 percent of the surviving moths under insectary conditions lived about 14 days.

Assuming that released, sterile male moth catches in gossyplure-baited traps reflected a measure of the number of released, sterile males in the area, mortality of the released insects was much higher than in the insectary, since few or no released sterile males were caught more than 7 days after last releases. Predation on released sterile insects was not measured but could have been a significant factor in reducing numbers of released insects.

The reported effects of radiation treatment on mass-reared pink bollworm male moth longevity under laboratory conditions are conflicting. Cheng and North (1972) found that longevity of male pink bollworm moths exposed to 20 krad was reduced. In contrast, Graham and others (1972) reported little or no effect on male pink bollworm moth longevity of 10 to 40 krad, as did Flint et al. (1973) after exposures of 10 to 25 krad. Henneberry et al. (1980) and Henneberry and Clayton (1981) reported variable results, observing significantly higher mortality of male moths after exposure to 10 to 15 krad in some experiments. In the above reported studies, longevity of female moths did not appear to be affected by irradiation at the same dosage levels. Released sterile moths in the present study were exposed to 20 krad, and, in view of the conflicting reports on male moth mortality, the possibility of an adverse effect of the radiation exposure on released male longevity must be considered.

The impact of other variables on the performance in the field of the released sterile males is also unknown. For example, Cheng and North (1972) and LaChance et al. (1973) found no effect of radiation (5 to 20 krad) on sperm transfer of mass-reared adult male moths. The number of spermatophores per mated female, however, increased when untreated females were mated to males exposed to 20 krad, indicating that untreated females were more receptive to repetitive mating after mating with the sterilized males. Females mated to males lacking the ability to effectively inseminate them tend to mate more often (Cheng and North 1972); however, if the sterile to native ratio remains at a high level, the probability of a second mating with a sterile insect should remain the same, as in the case of the first mating, and may not be a critical consideration.

LaChance et al. (1975) studied the reproductive performance of untreated and irradiated mass-reared and native pink bollworm strains to compare the effects of colonization and irradiation on the insects. The mating frequencies of males of both strains were similar after gamma radiation exposures of 0, 20, or 30 krad. But, native males transferred normal amounts of eupyrene sperm more often than mass-reared males, which

elicited greater oviposition response in mated females. The authors also found that the average number of spermatophores per mated mass-reared pink bollworm female moth was significantly higher than occurred in mated native females. They suggested that the process of colonization may have resulted in the selection of females more receptive to multiple mating than native females.

Under laboratory conditions, mass-reared, male pink bollworm moths do not mate as often with native females as with mass-reared females. However, mass-reared, female pink bollworm moths mate as often with mass-reared or native males (Henneberry et al. 1980 Henneberry and Clayton 1981). These results would partially explain the need for higher than theoretical (Knipling 1964) ratios of sterile to native insects to achieve population suppression (Richmond and Graham 1970, 1971; Bariola et al. 1973; Flint et al. 1974; and Flint et al. 1975).

Mass-reared pink bollworm moths have not compared favorably with native insects when measured by several other criteria. For example, Flint et al. (1975a) found that native males, as measured in flight-mill tests, were more active than mass-reared or mass-reared and irradiated males, but no difference occurred between mass-reared, irradiated, or untreated moths. Bariola (1978) reported further evidence of the lack of performance of mass-reared pink bollworm moths: their rate of reproduction in field cages was only one-tenth that of native overwintered moths.

The possibility of genetic selection of a trait(s) that results in poor mating interaction of released sterile pink bollworm males with St. Croix females could explain some of the results obtained in the present study. Boller (1972) suggested that, during the early stages of insect colonization, intense selection pressure may occur for individual insects that are adapted to survival on defined diets, artificial oviposition substrates, and restricted mating habitats. The reproductive performance of such individuals when released in the field might very well be adversely affected in relation to mating interactions with their native counterparts.

Our results indicate that mass-reared, irradiated pink bollworm males disperse greater distances than reported by Flint et al. (1975b). However, their tests were conducted in 6- to 16-ha cottonfields with traps positioned to measure capture of released moths no further than 610 m from the moth release site. Moth releases in the present study were made in a cotton plot with plants containing squares, flowers, and

bolls. The availability and attractiveness of the cotton may explain the large captures and tendency of the released moths to remain in the release plot. Also, both males and females were released, which may also influence the dispersal pattern, at least during the time moths are receptive to mating.

Van Steenwyk et al. (1978) reported that pink bollworm moths were highly mobile within a cotton planting during the growing season and that dispersal out of the field occurred predominately in late season.

The results of these studies did not show relatively long-range (up to 105 km) pink bollworm moth dispersal, as reported by Ohlendorf (1926) and Bariola et al. (1973). However, as indicated by McDonald and Loftin (1935) and Stern and Sevacherian (1978), long-range dispersal of this size may depend on vertical and horizontal wind movement to carry the insects. During the sterile moth release program on St. Croix, over 22 million moths were released, and none were caught in gossyplure traps at the Sea Island cotton locations over the island at distances of 3.0 to 20 km from the release area.

Efficient and dependable sampling techniques to determine the numbers of released sterile pink bollworm moths in the population in relation to the numbers of native moths need to be developed for existing and future sterile moth release programs. Ratios of sterile to St. Croix males in the present studies in gossyplure-baited traps over the entire release period ranged from 0.2:1 to 112.4:1 and averaged 32.4:1; in blacklight traps, 0.3 to 45.5:1 and averaged 14.8:1; and from hand collections, 0.07 to 36.6:1 and averaged 12.2:1. Although the highest numbers of released sterile males were consistently caught in gossyplure-baited traps, the fact that St. Croix male catches in the traps were negatively related to increasing sterile to St. Croix male ratios may suggest that the proportion of sterile male moths in the population was lower than shown by the gossyplure-baited trap catches. On many nights, over 100 sterile males were caught per gossyplure-baited Delta trap. Foster et al. (1977) reported that the efficiency of male moth captures in Delta traps decreased when traps became overloaded. Lingren et al. (1980) found the efficiency of Delta traps to be about 23 percent (number attracted vs. number captured), and male moth escapes increased after 50 males were in the trap. So, on some occasions, gossyplure-baited trap numbers may have caused underestimations of the released sterile to native male ratios.

Female moths were caught only in blacklight traps or by hand collection. In blacklight traps, released sterile female to St. Croix female ratios ranged from 0 to 54:1 and averaged 10:1; from hand collections, they ranged from 0.05 to 54.4:1 and average 13.3:1. Considering the numbers of sterile moths released (about 100,000 per release day), neither of these ratios appears to measure accurately the relative proportions of released sterile and St. Croix moths in the population during releases of sterile moths.

On mating tables, clipped-wing, mass-reared virgin females attracted and mated competitively with clipped-wing St. Croix females for released sterile or St. Croix males. Some of the mass-reared, clipped-wing females attracted and mated about 1 hour earlier than clipped-wing St. Croix females. But peak times of pink bollworm mating at Phoenix, Ariz., of 2:30 a.m. (Lingren et al. 1982) and at Brownsville, Tex., of 3:30 a.m. (Lukefahr and Griffin 1957) and peak captures of male moths in gossyplure-baited traps at 3:00 a.m. on Barbados (Ingram 1980) appear to agree well with peak numbers of hand-collected native mating pairs in the field and on mating tables between 3:00 and 4:00 a.m. in the present study. The earlier mating may be the result of differences in time zones, a laboratory-selected trait, or the mating-table environment. St. Croix daily times were 2 to 3 hours later than Phoenix, Ariz., times during these studies. But pink bollworm moths are readily re-entrained to existing photoperiods within 1 to 2 reverse light:dark cycles.

The effect of the earlier mating of released sterile insects on the efficiency of the sterile insects, in respect to suppression of a population development, in the present study is unknown. Raulston et al. (1976) found the receptivity of laboratory-reared <u>Heliothis virescens</u> (F.) females and mating of males occurred about 2 hours before that of native insects. The authors suggested that mixed-sex sterile releases of the species would result in high numbers of sterile male to sterile female mating, thereby reducing the numbers of sterile male to native female matings.

The results of the present study suggest that some released sterile females mated about 1 hour earlier than St. Croix females. But high percentages of St. Croix males responded to gossyplure-baited traps and clipped-wing, mass-reared females on mating tables during the earlier receptive period of the females, suggesting that St. Croix males would find and mate with released sterile females. Van Steenwyk et al. (1979) found that, when sterilized male and female moths were released in field cages with native moths, released sterile males and females were competitive with their native

counterparts in finding mates.

Releases of sterile females alone may be most effective for population suppression, and additional studies are needed to evaluate such releases. Also, the possible asynchrony of mass-reared, sterilized female moth mating receptivity and sterilized male mating response needs to be verified and its effect determined in sterile pink bollworm moth release programs in other areas. D. F. Keaveny III (unpublished data) found that sterile females on mating tables in the San Joaquin Valley, Calif., did not exhibit the earlier pheromone-calling activity that occurred on St. Croix.

The identification of mating interactions between released sterile moths and St. Croix moths was tried using the criteria of red spermatophores transferred by released mass-reared males and white spermatophores transferred by St. Croix males. Assuming that the laboratory results of cross matings of mass-reared moths from larvae reared on dyed and undyed artificial diet are valid for released mass-reared moths on St. Croix, then a part of the white spermatophores transferred from St. Croix males to released sterile moths were contaminated with dye in the female moth and identified as possibly the result of a sterile male mating. Also, the percentages of spermatophores that were transferred from released sterile males to St. Croix females were only accurately identified in the laboratory studies as red 88 percent of the time on the first male mating. Percentages of red spermatophores transferred on the second through the fourth mating decreased from 64 to 13 percent. So the data show that released sterile moth and St. Croix moth mating interactions occurred, but probably understate the numbers of times they occurred.

Bartlett (1979) described a pink bollworm mutant with melanic body color and named it "Sooty." The sooty character is inherited as a dominant autosomal mutation. Progeny resulting from a mating between a released homozygous Sooty moth and a native moth will have the black body color of Sooty. Bartlett and Lewis (1982) demonstrated the usefulness of the sooty body color marker in population dynamics and insect control programs such as the sterile insect release method. The use of the Sooty or some other genetic marker strain in future sterile release programs may provide a more accurate assessment of released sterile moth and native moth mating interactions.

All mating combinations of St. Croix and released sterile mating pairs were hand-collected in release plots. The interaction of released sterile moths with St. Croix moths in the population is further substantiated by the relatively

high (up to 15 percent) percentages of male larvae from cotton bolls found with chromosomal aberrations. These are indicative of released sterile to St. Croix moth matings, since over 95 percent of eggs from 20-krad male and female mating pairs fail to hatch (Cheng and North 1972, Graham et al. 1972, Henneberry et al. 1980). Further, adults produced from these larvae would be sterile (Cheng and North 1972, LaChance et al. 1973, Graham et al. 1972) and contribute further to population suppression of the insect (Knipling 1970).

The hand-collected mating pairs were the most direct evidence of the mating interactions of released sterile and St. Croix insects. The fact that fewer released sterile male to St. Croix female and released sterile female to St. Croix male mating pairs were found than expected and more St. Croix male to female mating pairs were collected than expected is a further indication of the noncompetitive nature of the sterilized, mass-reared, released moths.

Of the hand-collected St. Croix females, 80 to 100 percent were mated, with 1.4 to 3.7 spermatophores per female. High numbers of previously mated St. Croix females may have moved into the cotton plots from Sea Island cotton, from cultivated cotton plots outside the release area, or from alternate hosts that exist on the island as described by Loftin (1932). Also, high release rates (about 100,000 insects per release day) into relatively small experimental cotton plots result in unusually high moth population densities in the plots that may alter behavioral mating patterns of the insects. Kaae and Shorey (1973) found pink bollworm mating almost always occurred on the upper sides of cotton leaves on the outer perimeter and near the top of the cotton plant on calm nights. On windy nights, mating occurred at lower levels on the plant. The large numbers of sterile insects released that artificially inflated population densities may have affected the St. Croix insects to alter similar normal mating patterns or resulted in other overcrowding effects (Monroe 1969) that biased hand collections in favor of the released sterile moths.

Pink bollworm larval infestations in cotton bolls averaged 1.5 larvae per boll for the month before the start of releases of sterile moths. The numbers decreased to 0.3 larvae per boll after the large-scale release of about 100,000 sterile moths per release day in about 0.5 ha of cotton. There was no apparent effect on boll infestations from releases of sterile moths from January through April 1981 when ratios of sterile males to St. Croix males caught in gossyplure-baited traps averaged about 2:1. Reduced boll infestations occurred

during May through August when ratios of released sterile to St. Croix males average 72:1. Infestations increased in September 1981 through March 1982, ranging from 1 to 2.9 larvae per boll when the sterile to St. Croix male ratios averaged 20:1. But the 20:1 released sterile to St. Croix male ratio apparently had some population suppression effect since larval infestations increased from about one larva per boll to 3.7 larvae per boll during the 2 months immediately after the last release of sterile insects.

Boll infestations in cultivated commercial cotton types grown on the Kingshill and Virgin Islands Experiment Stations were higher throughout the experiment than in bolls in cultivated commercial cottons grown off the station as control plots or in Sea Island cotton. This probably occurred because of the continuous availability of host material afforded by the continued plantings on the experiment stations, whereas commercial cotton grown off the station was subject to dry weather conditions, and Sea Island cotton to both dry weather and inherent photoperiodic control of fruiting cycles, resulting in host-free periods in each case, of up to 5 months each year of the study.

Although no commercial cultivated cotton has been grown on St. Croix since 1927, pink bollworm populations have persisted on volunteer Sea Island cotton, as well as on other host plants (Loftin 1932). Larval infestations in Sea Island cotton bolls in the present study, as well as male moth trap catches, were lower than occurred in commercial cultivars grown for experimental purposes. Bolls of the volunteer Sea Island cotton are much smaller than those of commercial cultivars, which may account in part for lower infestation levels, or some pink bollworm plant resistance factors may exist in the Sea Island cottons on the island.

Boll infestations in the control plantings outside the sterile moth release area increased from <0.1 larva per boll in January 1981 to 2.9 larvae per boll in June 1981, and, although boll infestations were more variable in the 1981 to 1982 planting, a similar progressive population growth pattern was apparent as opposed to the significant decrease in boll infestations in cotton plots in the sterile moth release area during the same time.

Our inability to maintain the control cultivated cotton plots in good growing conditions outside the sterile moth release area prevented larger pink bollworm populations developing and larger, more consistent differences between boll infestations in the sterile moth release area and those developing in cultivated cotton in the control plots.

Since the St. Croix pink bollworm population in these studies was high, as evidenced by boll infestations averaging up to 3 or more larvae per boll, it is not possible to directly translate the data from the present studies in terms of expected results when native populations are very low. The sterile pink bollworm moth release method will be more effective when high released sterile to native moth ratios can be readily achieved and maintained. The problem of accurately measuring the impact of sterile moth release suppressive measures directed against very low, widely scattered, and migratory populations, as occurs in the San Joaquin Valley, needs to be determined with more research. Releases of sterile moths have been made during the cotton growing seasons in the San Joaquin Valley each year since 1968. Native male moths have been trapped in the valley each year of the program and larvae found in bolls in each of 3 years. Further, it has been demonstrated that overwintering larvae can survive and emerge in the spring in the Bakersfield area (A. C. Bartlett and R. T. Staten, unpublished data). So on the basis of indirect evidence, as well as the results of the present study, it appears that the releases of sterile moths that maintain average sterile to native ratios of more than 200:1 (Knipling 1978) throughout the season have prevented the establishment of the insect in the area.

The results of the present study show that mating interactions of released sterile moths and St. Croix moths occurred. Established larval infestations in bolls were reduced as a result of the release of sterile moths. These results were obtained when conditions for pink bollworm reproduction were optimized by providing a continuous source of cotton fruiting forms (squares and bolls) for oviposition and larval food.

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